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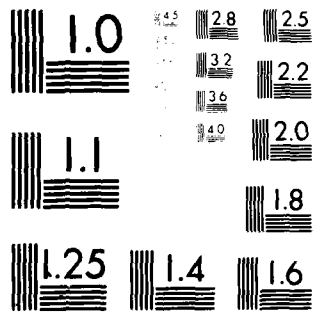
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DEPARTMENT OF GEOPHYSICAL SCIENCES
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERISTY
NORFOLK, VIRGINIA

Technical Report GSTR-82-1

EVALUATION OF EXTENDED PERIOD
FORECASTING TECHNIQUE

By

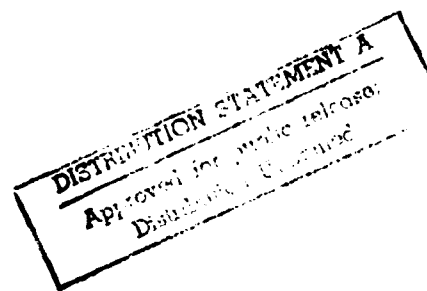
Earl C. Kindle, Principal Investigator

Final Report
For period June 1, 1977 - December 31, 1981

Prepared for the
Office of Naval Research
Department of the Navy
800 N. Quincy Street
Arlington, Virginia 22217

Under
Contract N00014-77-C-0377

January 1982



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SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
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Submitted by the
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P.O. Box 6369
Norfolk, Virginia 23508-0369



January 1982



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EVALUATION OF EXTENDED PERIOD FORECASTING TECHNIQUE

By

Earl C. Kindle

INTRODUCTION

This report summarizes work performed under ONR Contract No. N00014-77-C-0377 during the period June 1, 1977 to December 31, 1981:

- (1) Section I is a condensed summary of research results, and briefly outlines the work described in detail in Sections II and III.
- (2) Section II describes a statistical analysis which correlates characteristic North American weather patterns with solar activity. This will be submitted to the AMS Journal of Applied Meteorology for publication.
- (3) Section III describes an investigation of persistent weather regimes as associated with characteristic circulation features and solar activity. This will be condensed and submitted to the AMS Monthly Weather Review for publication.
- (4) Section IV is a paper that was prepared during early stages of the grant period for presentation at the Symposium/Workshop on Solar Terrestrial Influences on Weather and Climate, held at Ohio State University on July 24-28, 1978. It provides an analysis of the current nature of the problem and a description of a proposed mechanism by which variations in solar activity might influence terrestrial circulation systems.

SECTION I

CONDENSED SUMMARY OF
RESEARCH RESULTS

By

Earl C. Kindle

CONDENSED SUMMARY OF RESEARCH RESULTS

By

Earl C. Kindle

Statistical Analysis of Solar Activity and Terrestrial Weather Patterns

This phase of the research was conducted by Mr. Boyd E. Quate and Mr. Hermann Wobus, who completed extensive statistical analyses comparing solar data (and in some cases moon phase statistics) with terrestrial circulation patterns and forecasts of mean monthly temperatures for Norfolk, Virginia (see Section II of this report).

In the initial phases of their work Messrs. Quate and Wobus used a 27-year period of 500-mb data and characterized circulation patterns for 3 regions of North America: the west coast of the United States, central United States, and the east coast of the United States. They classified these systems in terms of the existence of ridges, troughs, closed lows, and not defined patterns. In their first step they computed serial correlations between these circulation systems using time lags ranging from 1 to 100 days. These lag correlations showed a definite periodicity in the existence of these circulation systems which is shown in Figure 1 of the Quate/Wobus report (Section II of this document) which is repeated on the following page.

In extensive subsequent efforts, correlations of Northern Hemispheric circulation regimes were computed using a combination of recorded sunspot activity and phases of the moon. These again indicated provocative correlations at quasi-discrete lag intervals with peak correlations running between 0.3 and 0.4 at the more significant lag periods, and between 0.1 and 0.2 for the lower points in the lag time scale. Results of these experiments are provided in Figures 18 to 36 of Section II. For sake of illustration, Figures 24 and 25 are repeated here.

In addition to the foregoing, Quate also used a selected nine-year period of sunspot and weather data for Norfolk, Virginia, with which he

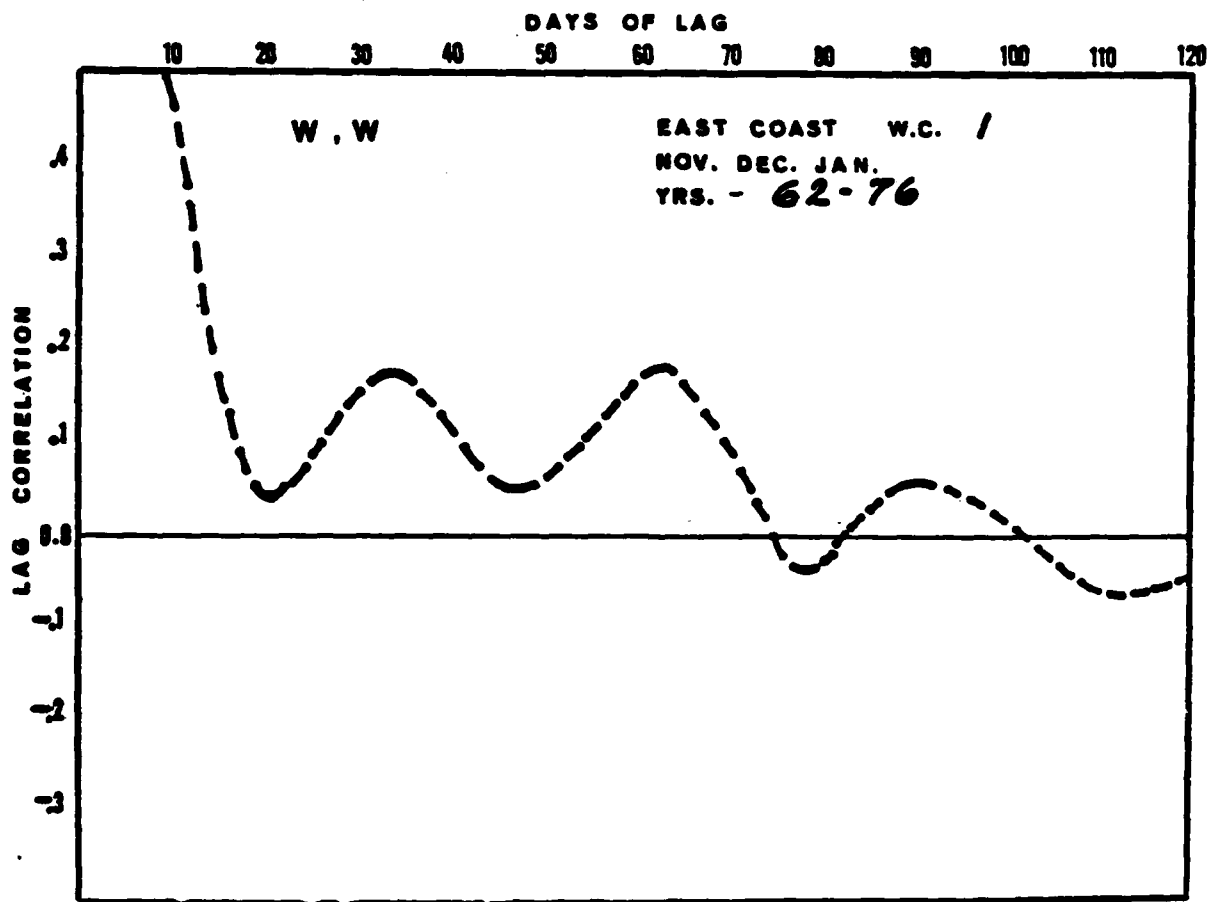


Figure 1. Correlation between current weather and subsequent weather over the east coast of North America.

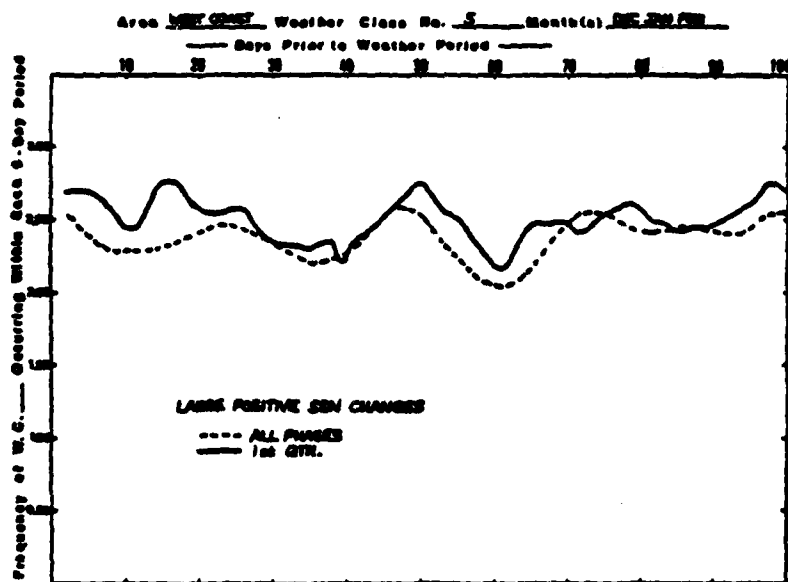


Figure 24. Frequency of occurrence of weather class No. 5 when DSS values were large positive values and occurred during the first quarter of the winter months.

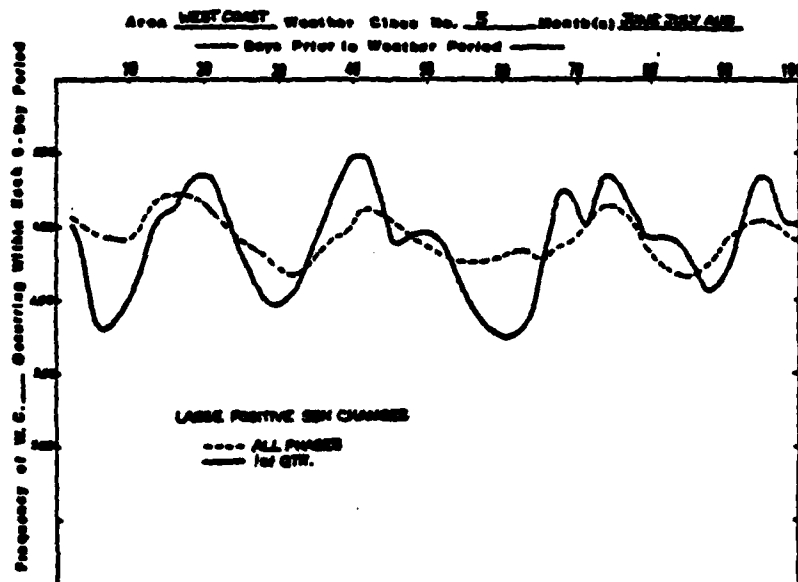


Figure 25. Frequency of occurrence of weather class No. 5 when DSS values were large positive values and occurred during the first quarter of the summer months.

developed prediction equations for the mean monthly temperature anomaly for various seasons of the year. These prediction statistics did indicate a degree of skill, but showed a definite preference for particular months during the year. These results are shown in Tables 1, 2, and 3 of Section II, and Table 1 is repeated on the following page.

While the correlation coefficients in Table 1, which range between 0.2 and 0.4, are not compelling, they are highly suggestive, even provocative. In retrospect, when one considers the total complexity of terrestrial weather, which involves many physical heat reservoirs (e.g. the ocean, atmosphere, and land surface as well as complex spectral/scale reservoirs for heat, moisture, and momentum), one would be naive to expect a single forcing function as qualitatively subtle as the solar variability to have a small level of control over the weather events. According, the degree of skill shown in the statistical prediction and the correlation statistics derived by the authors are probably what should be expected. In any event, these results should be useful and will be submitted to the AMS Journal of Applied Meteorology for publication.

At this point a clear reason for any solar variability effect on the Earth's weather has not been defined. This is a particularly difficult problem since with present knowledge of solar emissions the magnitude of the solar heat flux variability is much too small to have any direct effect on a corresponding variability in the Earth's weather. Nonetheless, the results of this work do indicate something positive and should be further investigated.

Analysis of Statistical Weather Regimes

On the basis of early results in Quate and Wobus's work, it was concluded that the complexity of the interaction between all the possible forcing functions would limit the collective influence of one or two of these such as solar activity and/or phases of the moon. In fact, it would appear that if solar activity exerted significant influence on terrestrial weather it would most likely become evident if some of the high-frequency variability could be smoothed out of the statistics. It was hoped that monthly or

Table 1. Monthly average temperature forecasts for Norfolk, Virginia for the month of February using the nine prior years of SIGMA DSS and SIGMA DAp.

	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>	<u>Jan.</u>
FORECAST ERROR	2.7°	3.2°	3.3°	2.7°	3.3°	3.2°	2.9°	3.2°	3.3°	3.3°
DEPARTURE FROM NORMAL	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°
FORECAST WINS	19	18	17	21	14	18	18	16	15	14
FORECAST TIES	6	7	4	5	7	5	4	5	7	4
FORECAST LOSSES	11	11	15	10	15	13	14	15	14	18

seasonal temperatures, as well as monthly or seasonal circulation patterns, would be a means of accomplishing this, and appropriate statistical studies were conducted but did not show any significant increase in correlation coefficients between the solar activity vs. terrestrial weather correlations.

For many years it has been noticed that there is a strong serial correlation in terrestrial weather: i.e., the weather of any given season or extended period has a higher correlation with this season or period than it does with its climatic average, indicating a periodic and, it is hoped, deterministic occurrence of prolonged weather regimes. Since improved ability in the prediction of the onset or termination of prolonged weather regimes would have great socioeconomic value, Mr. Steven Scherrer elected to search for possible correlations between the nature of these regimes and solar activity as the subject of his Master's thesis, presented in Section III of this report.

To accomplish this objective, the first step in this phase of research was an attempt to define categories of "persistent regime" and to search for synoptic properties associated with their onset and termination. One negative result of this research was the discovery that persistent regimes are very difficult to define in a systematic way. A procedure for defining weather regimes and statistical analysis of their occurrence involves a major portion of the effort in this phase and revealed several interesting properties.

The next step in this research program was an attempt to correlate the onset and termination of various regimes with the 27-year record of circulation systems. These correlations are described in Figures 13 to 16 of Section III. Figure 16 is repeated here for illustrative purposes.

In the third step of this research phase, an attempt was made to correlate solar activity with the average lengths of cold and warm regimes for the winter season. Results of this research are described in Figures 29 to 33 of Section III. Figure 33 is repeated here for illustrative purposes.

In summarizing results of this phase of the research, two quite useful statistical relationships were developed:

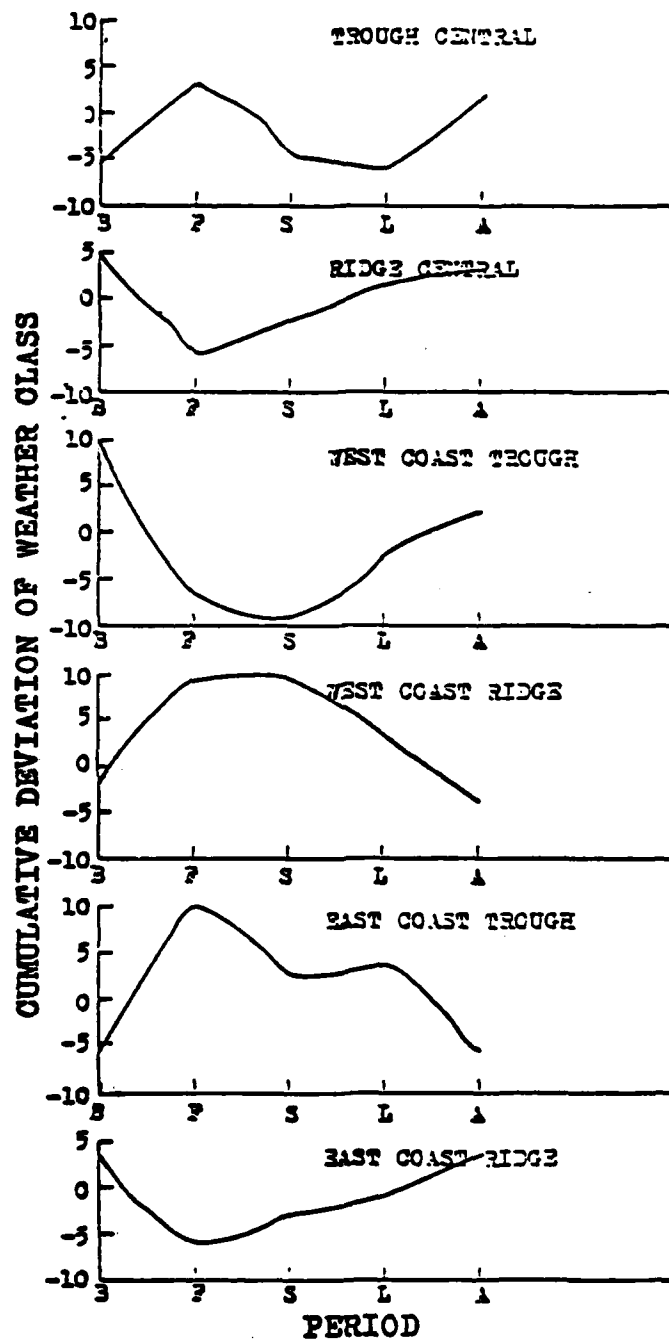


Figure 16. Cumulative deviation of weather class for 3 geographical regions of the U.S. for 10-day periods before (B), during the first 10 days (F), during the second 10 days (S), during the last 7 days (L), and after a 20-day cold regime (A).

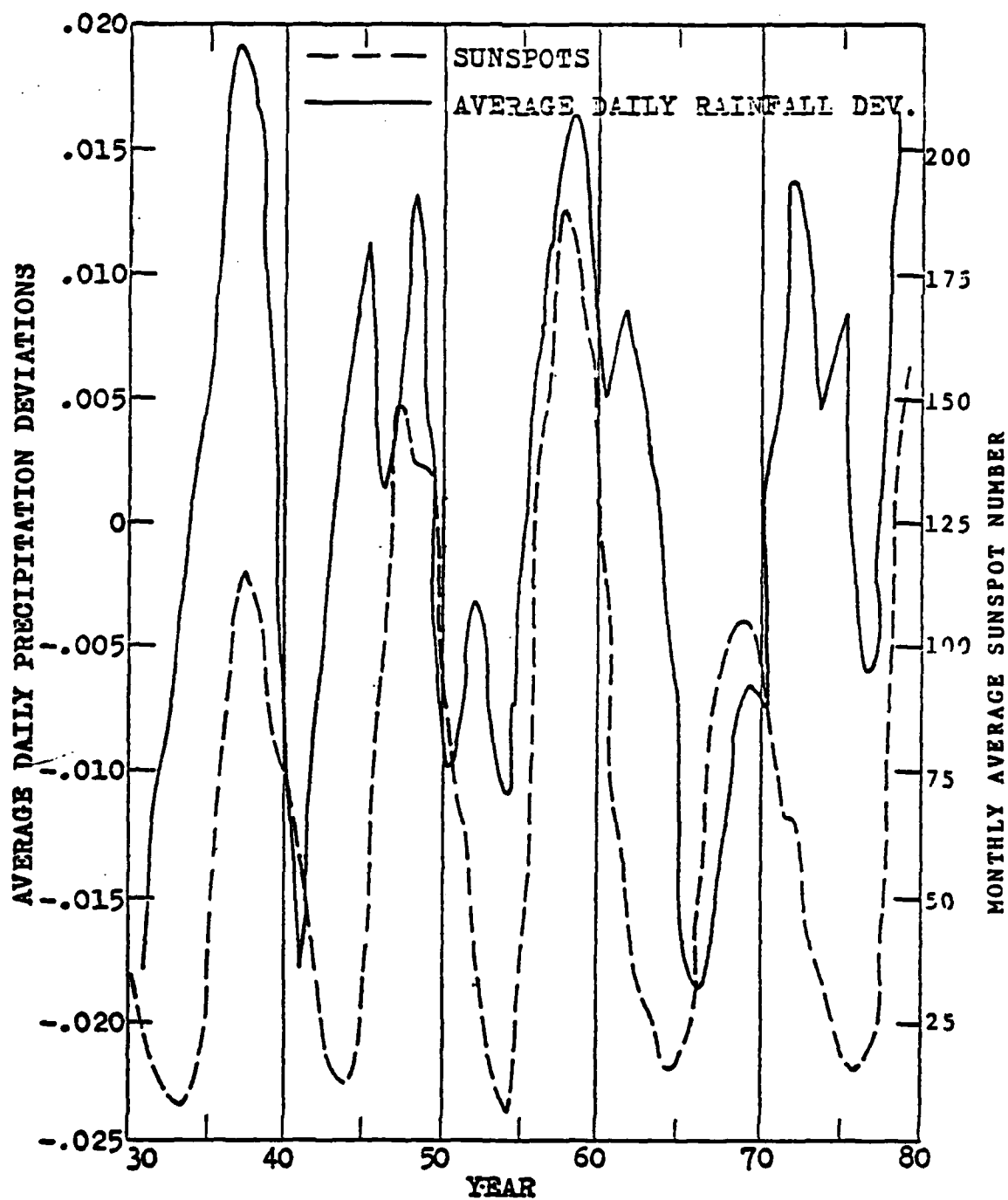


Figure 33. Plot of monthly average sunspot number against the average daily precipitation deviation for five-day periods for the period 1930-1979.

- (1) The relationships between the onset and termination of various regimes with characteristic 500-mb circulation patterns do provide some techniques that could have quite useful forecasting values; and
- (2) Again, the curves comparing the average length of weather regimes with solar activity are provocative and, even as they are defined herein, should be of use in extended period forecasting.

Mr. Scherrer's report is a very interesting and significant piece of work and clearly should be condensed and published. Mr. Scherrer has since completed his formal education at Old Dominion University and has taken a professional job, but he is being encouraged to condense his thesis for submission to the Monthly Weather Review for publication. If he is unable to do so in the next few months, the article may be reworked as a joint publication by Scherrer and Kindle and submitted at that time.

SECTION II

OBJECTIVE TECHNIQUES OF USING SOLAR DATA
TO PREDICT MONTHLY AVERAGE TEMPERATURES
AND WEATHER PATTERNS OVER NORTH AMERICA

By

Boyd E. Quate and Hermann B. Wobus

OBJECTIVE TECHNIQUES OF USING SOLAR DATA
TO PREDICT MONTHLY AVERAGE TEMPERATURES
AND WEATHER PATTERNS OVER NORTH AMERICA.

- - - - - Final Report - - - - -

By

Boyd E. Quate, Meteorologist
QUATE ASSOCIATES
Suffolk, Virginia

and

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OLD DOMINION UNIVERSITY
Norfolk, Virginia

December 1981

OBJECTIVE TECHNIQUES OF USING SOLAR DATA TO PREDICT MONTHLY AVERAGE
TEMPERATURES AND WEATHER PATTERNS OVER NORTH AMERICA.

ABSTRACT

The past four years of research work has produced a technique that allows the use of solar data in a multiple linear regression equation to predict certain weather parameters at any given locality. The method is capable of predictions up to ten months in advance. The method can be used for any station where ten or more years of historical data is on record. To illustrate: Solar data for the month of July can be used to predict the monthly average temperatures for the following February. Solar data for the month of October can be used to forecast June temperatures. Data from February can be used to forecast October temperatures. The table below illustrates some of the results obtained by this method.

COMPARISON OF FORECAST RESULTS VERSUS RESULTS USING CLIMATOLOGICAL AVERAGES¹
FOR MONTHLY AVERAGE TEMPERATURES AT NORFOLK, VIRGINIA.

<u>Forecast Month</u>	<u>February</u>	<u>June</u>	<u>October</u>
Number of Forecasts	36	69	36
Average Error of FORECASTS	2.7° F.	1.7° F.	2.2° F
Average Error of Climatological Forecasts	3.1° F.	1.7° F.	2.3° F.
<u>Percent of Total Years</u>			
When FORECAST was 'Best'.	58%	35%	48%
When FORECAST 'Lost'	28%	29%	36%
FORECAST and Climatology were 'Tied'.	14%	36%	28%

(1) Climatological Averages as herein defined are the 'normal' or long-term averages for the years 1941-1970, inclusive, as used by the National Weather Service.

A technique using a different approach was also developed whereby the pressure patterns at the 500 mb. level over North American could also be predicted from 1 to 100 days in advance. This alternate method utilizes changes in the sunspot numbers as a base. Timing is based upon the lunar month and the four phases of the moon.

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INTRODUCTION

Significant improvements in long range weather or climatic forecasts can produce tremendous societal yields. The benefits in both dollars and safety to society and the military are probably beyond calculation. Of all the fields of meteorological research, this type should produce the most in both benefits and the advancement of the present "state-of-the-art".

At Old Dominion we have been working on the problem of utilizing solar data as a basis for making extended period forecasts. Progress has been slow and oftentimes frustrating. More than 200 different computer programs have been developed and tested. Most were rejected because of nil results. However, a few did show promise of being acceptable as 'tools' for the purpose of making long range weather forecasts.

There are several approaches that one can take in trying to develop a long range weather forecasting method. Dynamic modeling, of course, would be ideal, if possible. However, at the present time, dynamic modeling can only project weather patterns 4 or 5 days, with very serious deterioration after that. Another method might be, one based upon more exact knowledge of the mechanism or physical linkage between solar activity and the earth's weather patterns. but todate, that linkage is not clearly understood. To us, the most logical approach to trying to solve the sun-weather riddle was to attempt to find a 'control'. By control, we mean, if an event can be observed and measured in realtime, have some relationship with future weather events, then this solar event can be used as a basis for making the long range forecasts, in spite of the fact we do not completely understand the mechanism behind such relationships. Our argument is that if such an event or events can be found, then the problem is simply one of identification and classification. We believe we have found a few solar events that fulfill the requirements of our hypothesis. These events are: "Changes in sunspot activity" and "solar flare activity".

The use of solar data as a tool for making future weather forecasts is nearly as old as the concept of solar activity itself. Probably the first to suggest solar influences on the earths weather was an Italian Jesuit priest by the name of Riccoli, who claimed back in 1651, that he had found changes in the regions weather were associated with the number of spots on the sun. William Herschel, in 1801, reported a relationship between sunspots and the weather conditions affecting the wheat crop in Britain. Langley and Abbott, early in the 20th Century, measured the variability of the solar

output. (Their work was almost completely ignored by nearly all their scientific colleagues who claimed that the solar output was constant, thus their work was wrong. It may be of interest to note that satellite data taken recently has confirmed that the solar constant is not constant but has a variation much like that reported by Langley and Abbott.) In 1915 H.H. Clayton with the Argentina weather service reported he also had found a relationship between variation in the solar output and the temperature, rainfall and barometric pressure, and like Abbott could use this information to make long range weather forecasts.

Hurd C. Willett,¹ professor of meteorology at the Massachusetts of Technology reported in 1945:

"-----the major changes in the behavior patterns of the earths general circulation cannot be fully explained primarily by the internal dynamics of the earth-atmosphere system. Thus it was decided to look for extra-terrestrial sources of disturbances and control of large scale changes of the hemispheric patterns of the general circulation. Variable solar activity was the most logical source of such disturbing impulses and no evidence turned up todate indicates that one need look further."

Roberts² in the late 1950s and Wilcox³ in the early 1960s found a significant correlation between the vorticity index over the northern hemisphere and the earths passage thru the solar magnetic sectors. This may have been the first direct evidence of a sun-weather relationship.

In the mid 1970s Markson⁴ concluded that there was evidence for: (1) a long-term secular effect in world wide thunderstorm activity which varies inversely with solar activity over the sunspot cycle and may result from changes in the atmospheric ionization from galactic cosmic rays which increasingly correlates with solar activity; and (2) short-term effects characterized by increases in the earth-to-ionosphere current flow and by increased thunderstorm activity for several days following solar flares.

In 1962 Quate⁵ noted what he called a "time-lag" relationship between the more significant changes in the number of spots on the sun and certain features of the earths weather patterns. It was his argument that if certain variables, such as sunspot numbers, were connected in some way with weather patterns occurring at a later date, then this in itself would be a useful forecasting tool. He suggested that by cataloguing the various types of SSN changes and the subsequent weather following each type of change one need only to classify the current sunspot pattern and then select similar

sunspot patterns from historical records. The weather following these analogue sunspot patterns could be used as a guide to forecasting the weather patterns to come following the current sunspot pattern.

This work evolved after a study of the thunderstorm activity over a banana plantation in the Republic of Panama. In 1957, 1958 and 1959 the thunderstorm activity was more severe and did more damage to the banana plantations than any previous year of record. In attempting to solve the problem of why those three years were so different, a conference with Dr. Charles C. Abbott in the Smithsonian Institution in Washington, D.C. suggested a possible connection with sunspot activity. Further work revealed that those same years were also years with the highest number of sunspots ever recorded. Continued work suggested a relationship between solar activity and the earth's weather patterns at the higher latitudes also, except at higher latitudes there seemed to be a time-lag effect of several months between changes in the sunspot numbers and the changes in the earth's weather patterns.

In 1976-77 Dr. Earl C. Kindle⁶ of the Old Dominion University in Norfolk became interested in investigating the potential sun-weather relationships as a long range forecasting method. In 1977 the Old Dominion Research Foundation initiated a research program to objectively test several theories and possibilities. The program funded by the Office of Naval Research, has now been completed. This report summarizes the major findings of this research work.

SECTION A

PREDICTING MONTHLY AVERAGE TEMPERATURES BY USING SOLAR VARIABLES IN A
MULTIPLE LINEAR REGRESSION EQUATION.

To test the hypothesis that certain solar variables have a possible relationship with the earth's weather, our first efforts were directed towards finding any possible relationships between individual solar variables and the various weather patterns. We first attempted to find the correlation between the current weather and the subsequent weather downstream from 1 to 120 days.

Figure 1 (below) shows the results of testing for Weather Class No. 1 over the East Coast of North America. (W.C. No. 1 is defined as a Closed Low at the 500 mb. level.) The reader will note three peaks in the graph. One at the 30-day lag date, one at the 60-day lag date, and a very small one at the 90-day lag date. Statistical tests show these values to have a low significance level.

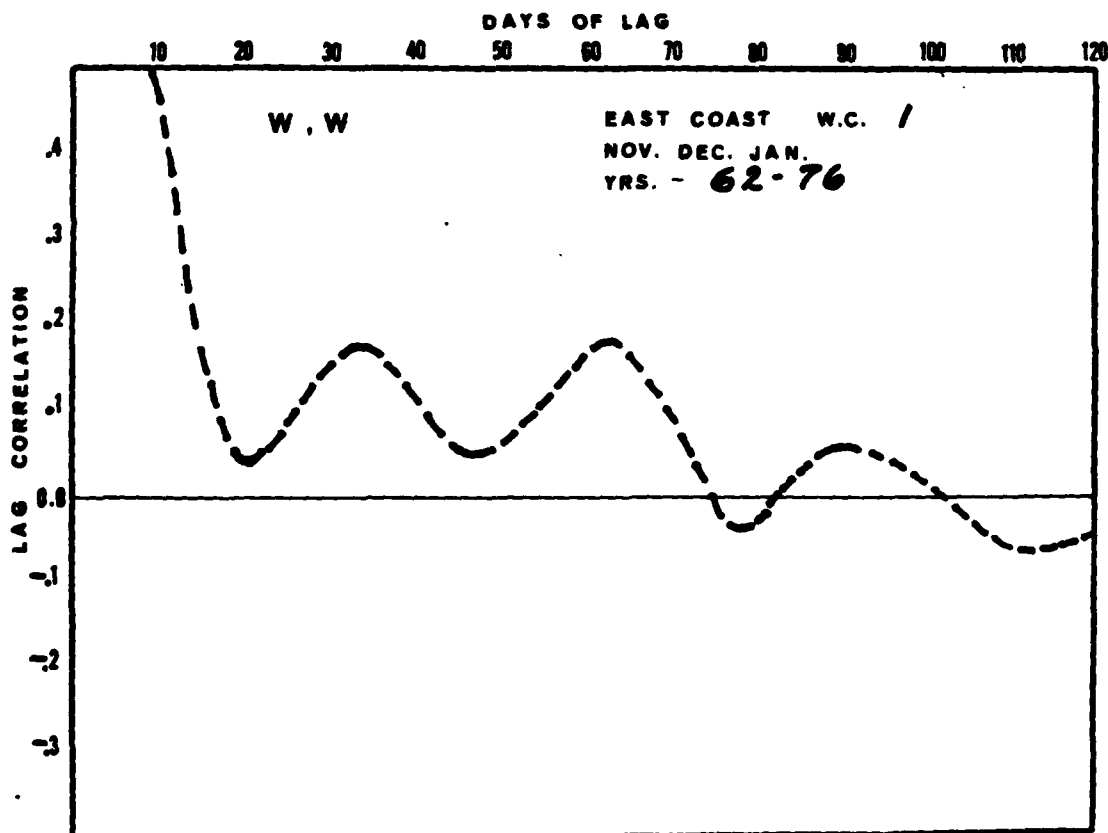


FIGURE 1. Correlation between Current Weather and Subsequent Weather over the East Coast of North America.

This chart shows that the correlation between the Zurich Sunspot Numbers and Weather Class No. 1 (Closed Lows at the 500 mb. level) over the East Coast of North America is highest when the weather has a 54 day lag behind the sunspot numbers.

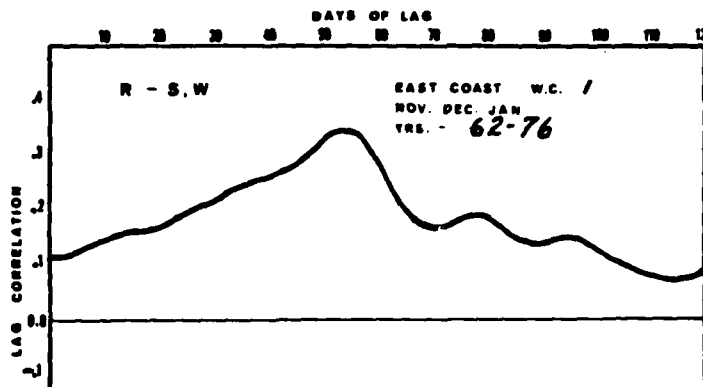


FIGURE 2. Correlation between current Sunspot Numbers and subsequent weather over the East Coast of North America.

This graph shows that the correlation between the Zurich Sunspot Numbers and Weather Class No. 1 (Closed Low at 500 mb.) over the East Coast of North America is highest near the 80 day time-lag interval for years with Low sunspot numbers and near the 70 day-time lag interval for years with High Sunspot numbers. However, years with High numbers are negative better than 90% of the time, whereas during Low sunspot years the correlations, although very weak, are mostly positive.

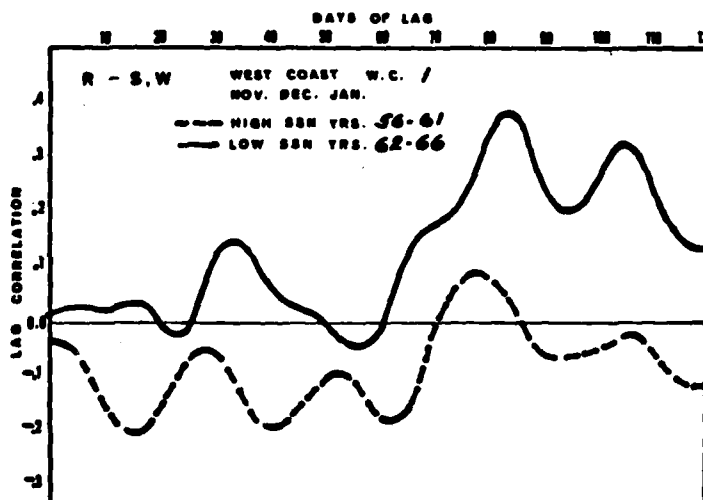


FIGURE 3. Correlation between current Sunspot Numbers and the subsequent weather over the East Coast of North America for years with low sunspot numbers (solid line) and years with High sunspot numbers (dashed line).

To test the hypothesis that more than one solar variable may be involved in influencing the earth's weather, a program was developed where a multiple linear regression equation was utilized.

The equation: $Z = C + A_1X + A_2Y$

where Z = Parameter to be forecast
 C = Coefficient of Determination
 A_1 = Coefficient of Variable X
 A_2 = Coefficient of Variable Y
 X = Solar Variable No. 1
 Y = Solar Variable No. 2

The coefficients A_1 and A_2 were determined by using the X , Y and Z data for 9 consecutive years. Then by inserting values for X and Y for the 10th year, our program predicts the value for Z for the 10th year.

The solar variables tested in our research work were:

\overline{SSN} --- (Average Sunspot Number)
 $\sigma \overline{SSN}$ --- (Variation of Sunspot Numbers)
 \overline{DSS} --- (Average DSS values)
 $\sigma \overline{DSS}$ --- (Variation of DSS values.)
 \overline{Ap} --- (Average Ap Index Value.)
 $\sigma \overline{Ap}$ --- (Variations of the Ap Index Values.)
 \overline{DAP} -- (Average of the DAP values.)
 $\sigma \overline{DAP}$ -- (Variations of the DAP values.)

SSN is defined as the Zurich Sunspot Number as furnished by Professor H. Waldmeier of the Swiss Federal Observatory, Zurich, Switzerland.

Ap is defined as the Earth's Geomagnetic Index value as furnished by the Environmental Data and Information Service of the National Oceanic and Atmospheric Administration, Boulder, Colorado.

DSS is defined as changes in the SSN values over a 10-day period and calculated according to this formula:

$$DSS = \frac{S_n - S_p}{S_n + S_p + K}$$

where, S_n = 5-day mean values of SSN for the most recent 5-day period.
 S_p = 5-day mean values of SSN for the 5-day period just prior to the S_n 5-day period.
 K = Normalizing factor. (We used $K = 40$.)

Although DSS values can range from +1.00 to -1.00, the upper quartile (25%) of our data was above +0.10 and the lowest quartile (25%) was below -0.10. We have identified the upper quartile data as "large positive increases" and the lowest quartile data as "large negative decreases".

Dap values were obtained with the same formula, except Ap values were used instead of SSN values.

Figure 4 illustrates an example of this computation.

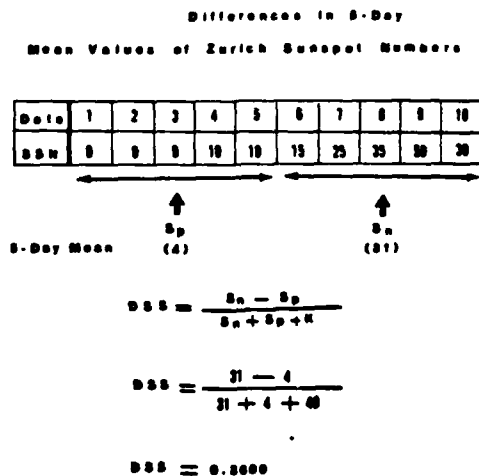


FIGURE 4
Differences in 5-Day Mean Values
of Zurich Sunspot Numbers (DSS).

Figure 5 is a graph of the daily SSN for the six month period of July thru December, 1957. The numbers below the curves are the $\overline{\text{SSN}}$ and σ_{SSN} values for each of the six months.

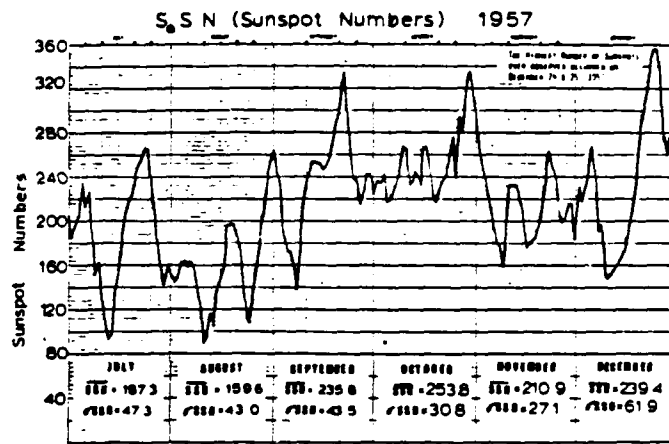


FIGURE 5. SSN Daily Values.

Figure 6 is a graph of the daily DSS values for the six month period of July thru December, 1957. The numbers below the curves are the $\overline{\text{DSS}}$ and σ_{DSS} values for each of the six months.

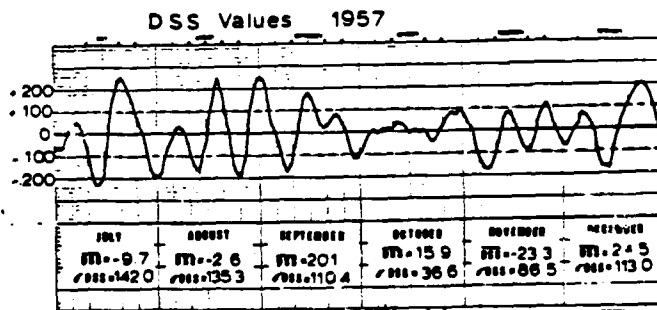


FIGURE 6. DSS Daily Values

Figure 7 is a graph of the daily A_p values for the six month period of July thru December 1957. The numbers below the plotted curves are the $\overline{A_p}$ and the σA_p values for each of the six months.

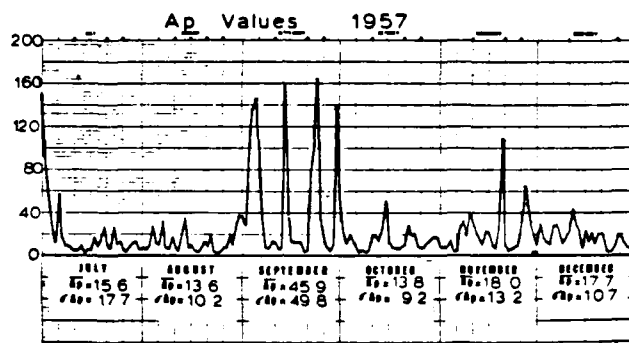


FIGURE 7. A_p Daily Values.

Figure 8 is a graph of the daily $D A_p$ values for the six month period of July thru December, 1957. The numbers below the plotted curves are the $\overline{D A_p}$ and the $\sigma D A_p$ values for each of the six months.

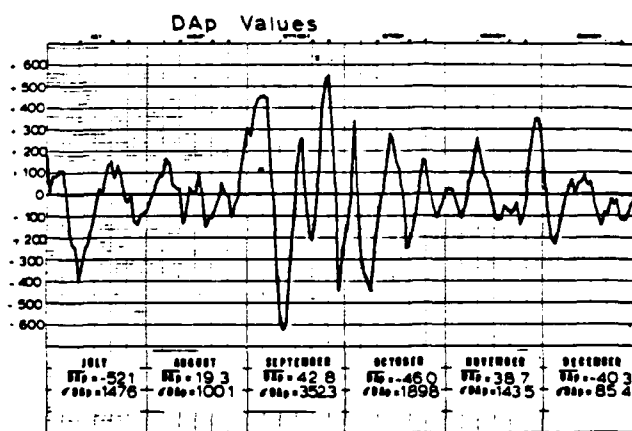


FIGURE 8. $D A_p$ Daily Values.

To test the usefulness of FORECASTS made using double solar variables in a multiple linear regression equation, we have used the forecasts based upon climatological averages as the base for comparison. If the difference between the actual temperature and the forecast temperature was less than the departure from normal value, the FORECAST was scored as a "WIN". If the departure from Normal was less than the FORECAST difference, then the FORECAST was scored as "LOST". If they were the same, the score was "TIED".

We have selected Norfolk, Virginia as an example, using Monthly Average Temperatures. The following three tables are examples of the results obtained when this technique is used to make FORECASTS:

TABLE I. Monthly Average Temperature Forecasts for Norfolk, Virginia for the month of FEBRUARY using the nine prior years of SIGMA DSS and SIGMA DAP for the months of:

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
FORECAST Error	2.7°	3.2°	3.3°	2.7°	3.3°	3.2°	2.9°	3.2°	3.3°	3.3°
Departure from Normal	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°	3.1°
FORECAST WINS	19	18	17	21	14	18	18	16	15	14
FORECAST TIES	6	7	4	5	7	5	4	5	7	4
FORECAST LOST	11	11	15	10	15	13	14	15	14	18

By using the solar variables SIGMA DSS and SIGMA DAP for the month of July, we noted that the average Forecast Error was only 2.7° Fahr. whereas if we had used climatological averages our error would have been 3.1°. Also by using July solar data the Forecast was more nearly correct 21 times or 58% of the time, whereas climatological averages (NORMAL) would have given the best answer only 10 times or 28% of the time. The FORECAST and climatology would have given the same error (TIED) 14% of the time.

Because the Geomagnetic Index Value (Ap) is only available since 1932 and because it requires the first nine years to establish the values of the various coefficients, we could only make forecasts for the years 1941 - 1977, inclusive or 36 forecasts.

TABLE II. Monthly Average Temperature Forecasts for Norfolk, Virginia for the month of JUNE using the nine prior years of SIGMA SSP AND SIGMA DSS data for the month of:

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
FORECAST Error	1.8°	1.8°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°
Departure From Normal	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°	1.7°
FORECAST WINS	24	21	25	29	28	28	23	18	27	28
FORECAST TIES	21	22	25	16	16	18	25	28	21	21
FORECAST LOST	24	26	19	24	25	23	21	23	21	20

By using the solar variables SIGMA SSP and SIGMA DSS for the month of October, we note that the average FORECAST Error was 1.7° Fahr., as compared to the same value using climatology. Also, by using October solar data the FORECAST for June would be correct 25 times or 38% of the time, whereas, climatology would have produced the best forecast only 19 times or 28% of the time. they would have Tied 25 times or 38% of the time.

Sunspot data is available for more than 100 years, thus in this example we started our test back in 1901, used the first 9 years to establish our coefficients giving us 69 years (1910 - 1977 inclusive) to make forecasts.

TABLE III. Monthly Average Temperature FORECASTS for Norfolk, Virginia for the month of OCTOBER, using the nine prior years of AVERAGE SSP and AVERAGE DAP data for the months of:

	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
FORECAST Error	2.3°	2.3°	2.2°	2.4°	2.5°	2.3°	2.3°	2.2°	2.3°	2.4°
Departure From Normal	2.3°	2.3°	2.3°	2.3°	2.3°	2.3°	2.3°	2.3°	2.3°	2.3°
FORECAST WINS	13	12	16	12	14	13	12	13	15	14
FORECAST TIES	12	14	10	12	6	12	11	10	7	8
FORECAST LOST	11	10	10	12	16	11	13	13	14	14

By using the solar variables AVERAGE SSP and AVERAGE DAP for the month of FEBRUARY, we note that the average FORECAST Error was 2.2° Fahr., whereas by using climatology the average error would have been 2.3° Fahr. Also, by using February solar data, the FORECAST 'won' 16 times or 48% of the time, whereas, the climatology 'won' only 10 times or 28% of the time. They 'tied' 10 times or 28% of the time.

Again we only had 36 years of data to work with in making the forecast, because one of our variables was based upon Geomagnetic data (Ap Index Values).

SECTION B

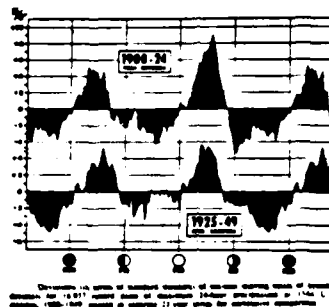
MOON-WEATHER RELATIONSHIPS

Brier,⁷ et al, have shown that rainfall over continental United States is correlated with the moons position as it circles the earth. They found rainfall records showing a period equal to half the synodic period of the moon. However, when they separated their rainfall data into years with high and low sunspot activity they found the lunar effect was much greater during quie solar periods (low sunspot years). In fact during the years with low sunspot numbers, the lunar cycle accounted for 65% of the variance in the data; whereas, during years of high sunspot numbers, the lunar cycle accounted for only 15% of the variance. This suggests that most of the variation in rainfall occurs during the years with low solar activity. Low rainfall means drought. Examples of low sunspot years and drought are the years of 1976-77, the 1952-54 period, and the early 1930s. Figure 9 is a reprint of charts as report by Brier in the USA and by Adderly and Bowen in New Zealand.)

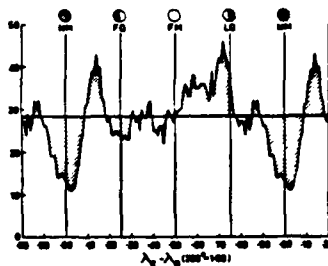
Quate⁸ in analyzing thunderstorm activity in the tropics found a similar relationship. He found that the number of thunderstorms occurring over the banana plantations in Panama had a high correlation with the various phases of the moon. Figure 10 is a summary of his data.

Lund⁹ analyzed daily observations of sunshine taken in Central and Northeastern United States during spring and summer. He found less than average sunshine during the first and third weeks of the lunar month and more than average sunshine during the second and fourth lunar weeks. In comparing "high" and "low" sunspot years he also found that the departures before FULL MOON were greater during the years with low sunspot activity than during the years with high sunspot activity. Figure 11 is a summary of Lund's data.

Markson¹⁰ has pointed out that while lunar tides in the atmosphere appear to exert an influence on rainfall they also play a significant role in some geophysical and upper atmosphere phenomena. He stated that it may be possible that certain lunar influences which have been attributed exclusively to tides are at least in part due to electrical mechanisms. That is, lunar periodicity in rainfall does not necessarily imply only tidal mechanism, but also modulation of solar corpuscular radiation.

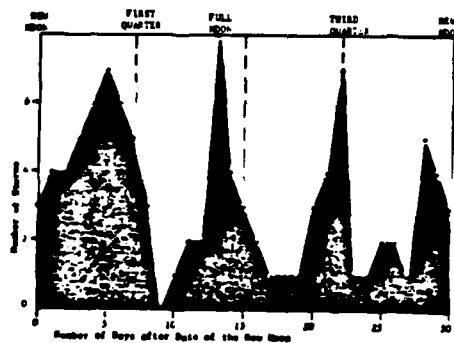


From Brier, Stanley & Woodbury, SCIENCE Vol. 137, 7 September 1962



From Brier, Stanley & Woodbury, SCIENCE Vol. 137, September 1962.

FIGURE 9. Precipitation correlated with Moon Phases, according to Brier.



(Data includes 100 cases from the 10 years of 1953-62, incl.)

From Quate - Chiriqui Land Company, Final Report 1963

FIGURE 10. Frequency of Thunderstorms over the banana plantations in Panama versus Moon Phases, according to Quate

SECTION C -- WEATHER PATTERNS AT THE 500 MB. LEVEL ASSOCIATED WITH CHANGES IN THE ZURICH SUNSPOT NUMBERS.

Summary

Analysis of 31 winter seasons (1946-76, inclusive) showed significant difference in the frequency of occurrence for both cyclonic and anticyclonic weather patterns when preceded by large positive or large negative changes in the Zurich Sunspot Numbers at time intervals of from 1 to 100 days. When the four phases of the Moon were considered, the magnitude of the changes increased.

The highest frequency of cyclonic weather patterns occurred during the FULL MOON phases when preceded by large positive changes in sunspot numbers at a time interval of 26 days and during the NEW MOON phases when preceded by large positive changes at time interval of 46 days. The highest frequency of occurrence of cyclonic weather patterns preceded by large negative changes was found at a time interval of 82 days for the NEW MOON Phases and a time interval of 90 days during the FULL MOON phases.

For anticyclonic weather patterns the highest frequency occurred during the NEW MOON phases when preceded by large positive changes in the sunspot numbers at a time interval of 38 days. When the changes were large negative the highest frequency of anticyclonic weather patterns occurred during the NEW MOON phases at time intervals of 52 days, 70 days, and at 96 days.

The data suggests a time-lag effect between solar activity as evidenced by large changes in the sunspot numbers and the earth's weather patterns, with a modification effect resulting from timing with the lunar phases.

The following charts illustrate the areas of investigation over North America and the type of Weather Patterns classified for this work.

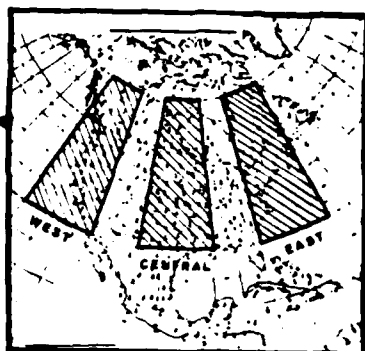


FIGURE 12. ZONES OF ANALYSIS

Three areas were studied in this investigation. Each area was bounded by 30° North Latitude on the South and 60° North Latitude on the North. The Longitude boundaries were:

1. WESTERN ZONE --- 115° West to 130° West Longitude
2. CENTRAL ZONE --- 90° West to 105° West Longitude.
3. EASTERN ZONE --- 65° West to 80° West Longitude.

Weather Classification:

The weather patterns in each of the above described zones were defined by the contour height lines at the 500-millibar level. The following charts illustrate the four different Weather Classes.

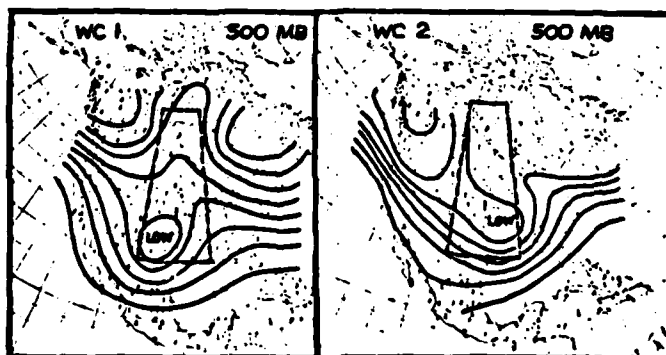


FIGURE 13. EXAMPLES OF WEATHER CLASS NO. 1 & 2.

Weather Class No. 1 was defined as a CLOSED LOW at the 500 mb. level.

Weather Class No. 2 was defined as a TROUGH of Low Pressure at 500 mbs.

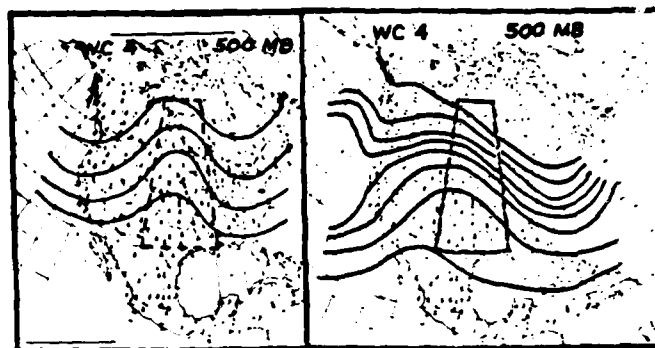


FIGURE 14. EXAMPLES OF WEATHER CLASS No. 4
Weather Class No. 4 was defined as a ridge of High pressure at 500 mbs.
(Anticyclonic Circulation patterns.)

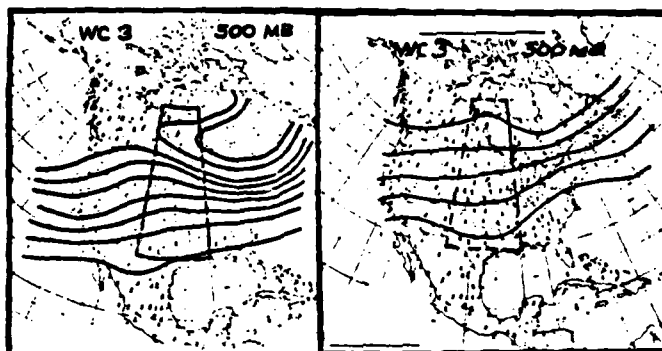


FIGURE 15. EXAMPLES OF WEATHER CLASS No. 3
Weather Class No. 3 was defined as a flat or indeterminate type of
circulation pattern at the 500 mb. level. Neither cyclonic or anticyclonic
circulation patterns dominate the areas in Weather Class No. 3.

MEAN VALUES of Weather Classes (\bar{X})

To establish a base for comparison purposes, the mean values of each weather class for each area for each season was computed. An example is shown graphically in Figure 16.

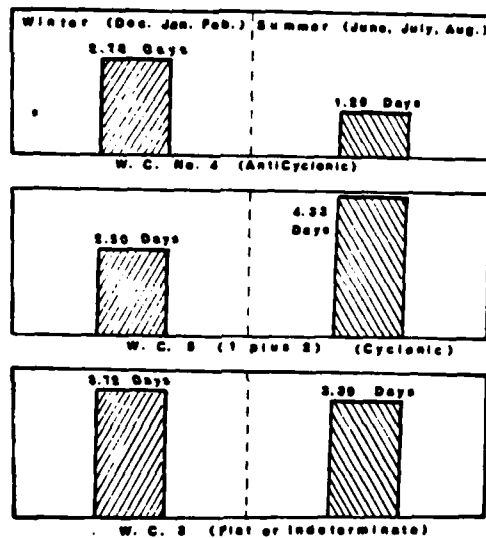
For Weather Class No. 4, during the 3 winter months of December, January and February, the mean value was found to be 2.79 days per 9-day segment; whereas, during the summer months the mean value was only 1.29 days per 9-day segment.

Weather Class No. 5 (cyclonic) had a mean value of 2.50 days per 9-days in the winter and a mean value of 4.33 days per 9-days in the summer.

Weather Class No. 3 had a mean value of 3.72 days per 9-days in the winter and 3.39 days per 9-days in the summer.

For The WEST:

The Mean Values (\bar{X}) for the Frequency of Occurrence of Each Weather Class is shown in the Diagrams below



One phase of our investigations required that we determine the frequency of occurrence for each weather class as a function of the different categories of DSS values. The technique is described briefly as follows:

First, the number of cases of the various weather classes occurring in each 9-day segment of the period being analyzed was computed.

Second, the DSS values were computed for each time-lage day from 1 to 100 prior to all the 9-day segments of the period.

Third, a summation of the frequency of each weather class occurring in all the 9-day segments following each time-lag day was then made. For example, the number of times, say Weather Class No. 4, occurred in each 9-day segment following time-lage day 1 was summed, then the number of times following time-lag day 2 was summed, then time-lag day 3, etc., out until all 100 days had been totaled.

Fourth a summation of each weather class following each time-lage day was the averaged for only those cases preceeded by the pre-selected DSS values. For example, in analysing Large positive DSS values the average frequency of occurrence was determined only for thos days following DSS values equal to or greater than +0.10 (the upper quartile).

Figure 17 illustrates one example.

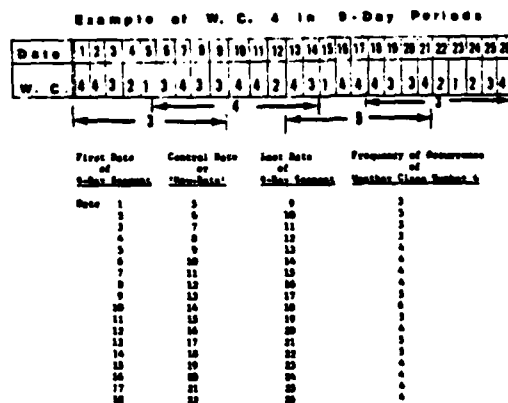


FIGURE 17. AN EXAMPLE OF FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4

Our investigation was restricted to the use of the 500 millibar data and maps for this phase. The data used therefore covers the 31 year period of January 1, 1946 thru December 31, 1976.

Each year was subdivided into four seasons as follows:

Winter -- December, January and February

Spring -- March, April and May

Summer -- June, July and August

Autumn -- September, October and November.

The test for lunar influences required the lunar month to be divided as follows:

First Quarter -- A 7-day period centered on the dates 7 days after the date of the New Moon.

Full Moon -- A 7-day period centered on the dates 14 days prior to the date of the New Moon.

Third Quarter -- A 7-day period center on the dates 7 days before the dates of the New Moon.

New Moon -- A 7-day period centered on the dates of the New Moon.

Sunspot numbers used throughout this study were those furnished by Prof. H.Waldmeier, Swiss Federal Observatory, Zurich, Switzerland.

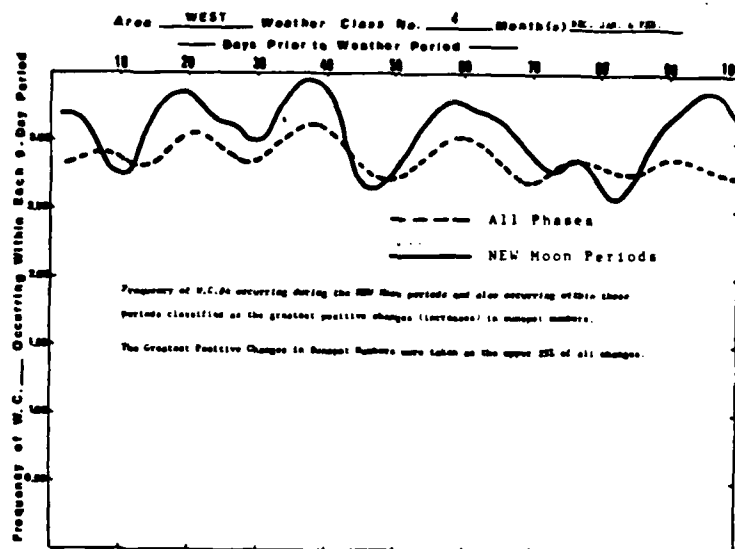


FIGURE 18. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 (Anticyclonic). Only for the winter months and for periods following DSS values in the upper quartile occurring during the NEWMOON periods. (Dashed lines show frequency of occurrence for all phases.)

Note: peak values occurring just prior to 20 days, 40 days, 60 days and 100 days. Highest values occur just prior to 40 days.

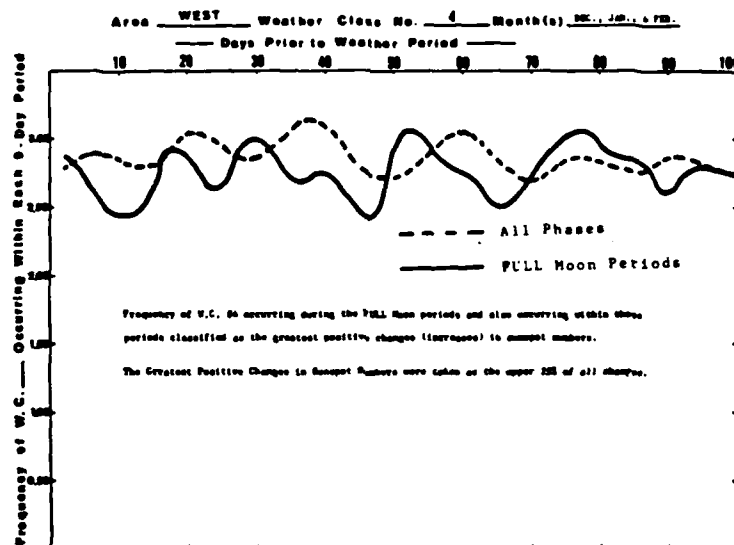


FIGURE 19. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 (Anticyclonic). Winter months only, following those periods when the DSS values were in the upper quartile during the FULL MOON periods.

In this case the peaks are less significant than those with New Moon timing.

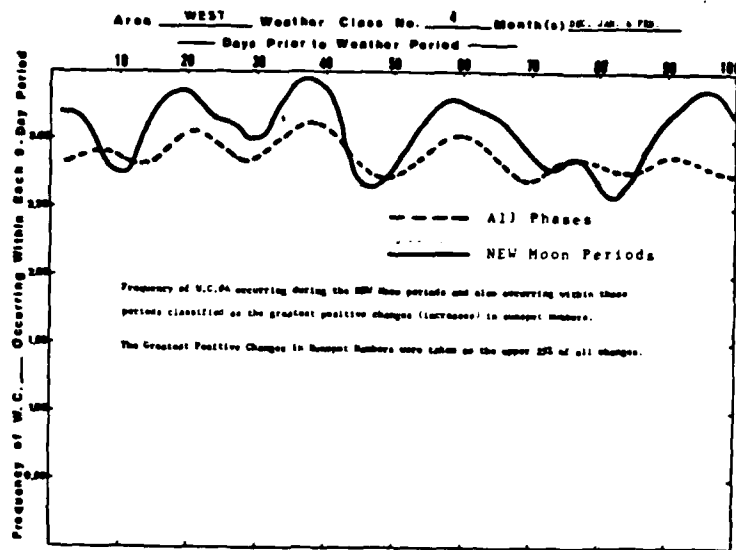


FIGURE 18. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 (Anticyclonic). Only for the winter months and for periods following DSS values in the upper quartile occurring during the NEWMOON periods.

(Dashed lines show frequency of occurrence for all phases.)

Note: peak values occurring just prior to 20 days, 40 days, 60 days and 100 days. Highest values occur just prior to 40 days.

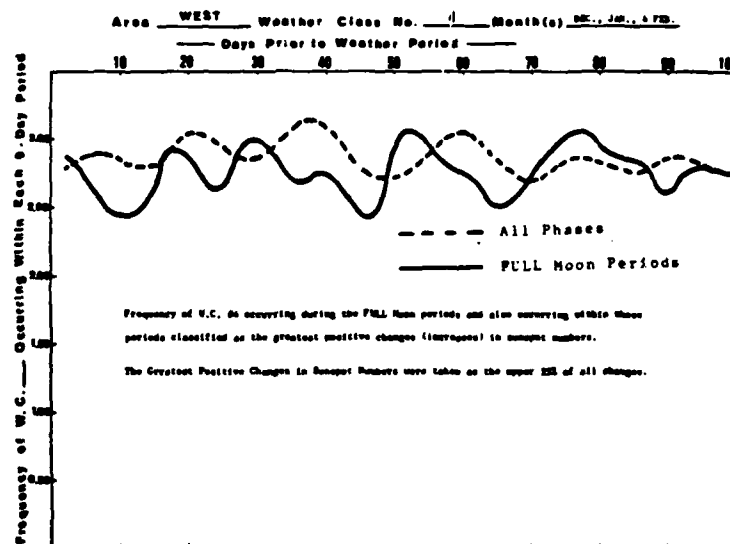


FIGURE 19. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 (Anticyclonic). Winter months only, following those periods when the DSS values were in the upper quartile during the FULL MOON periods.

In this case the peaks are less significant than those with New Moon timing.

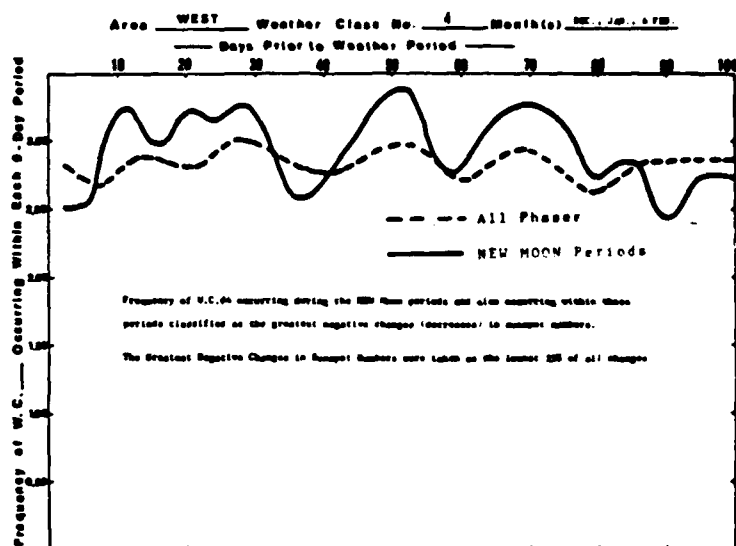


FIGURE 20. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 (Anticyclonic). During the winter months when the DSS values were in the Lowest quartile for the NEW MOON period.

Here we note that peak values were reached near the 50 day and the 70 day time-lag. At 50 days the value is near 3.50 days per 9-day segment.

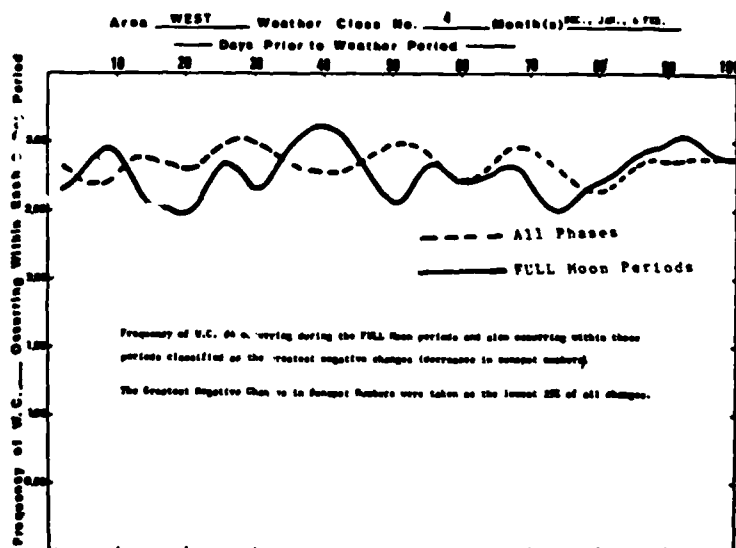


FIGURE 21. FREQUENCY OF OCCURRENCE FOR WEATHER CLASS No. 4 (Anticyclonic). During the winter months when the DSS values were in the Lowest Quartile for the FULL MOON period.

The peaks in this case are not significant.

The two charts below compare the Frequency of Occurrence for the New Moon and Full Moon phases.

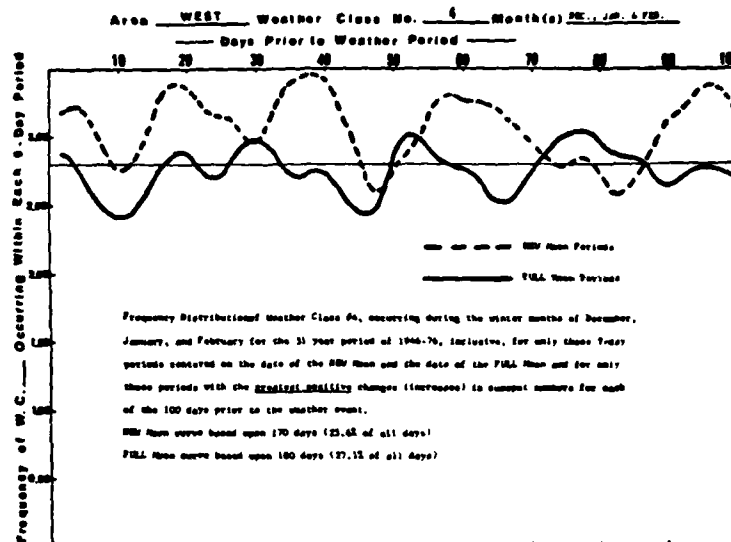


FIGURE 22. FREQUENCY OF OCCURRENCE COMPARING NEW MOON WITH FULL MOON, WHEN DSS VALUES WERE IN THE UPPER QUARTILE.

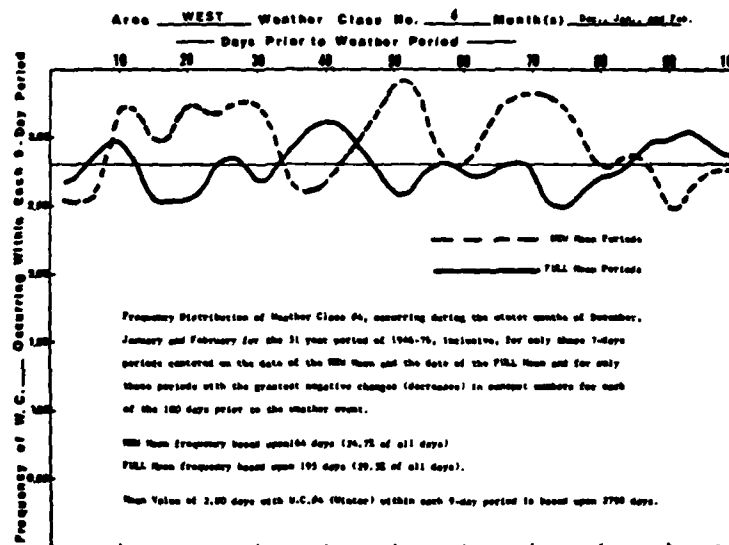


FIGURE 23. FREQUENCY OF OCCURRENCE COMPARING NEW MOON WITH FULL MOON, WHEN DSS VALUES WERE IN THE LOWEST QUARTILE.

These two charts show the comparison between winter and summer for Weather Class No. 5 (cyclonic).

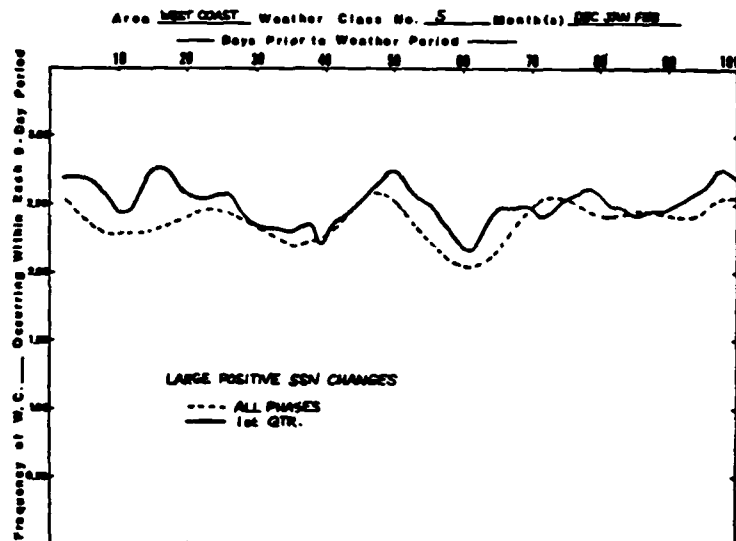


FIGURE 24. FREQUENCY OF OCCURRENCE OF WEATHER CLASS NO. 5 WHEN DSS VALUES WERE LARGE POSITIVE VALUES AND OCCURRED DURING THE 1st QUARTER OF THE WINTER MONTHS.

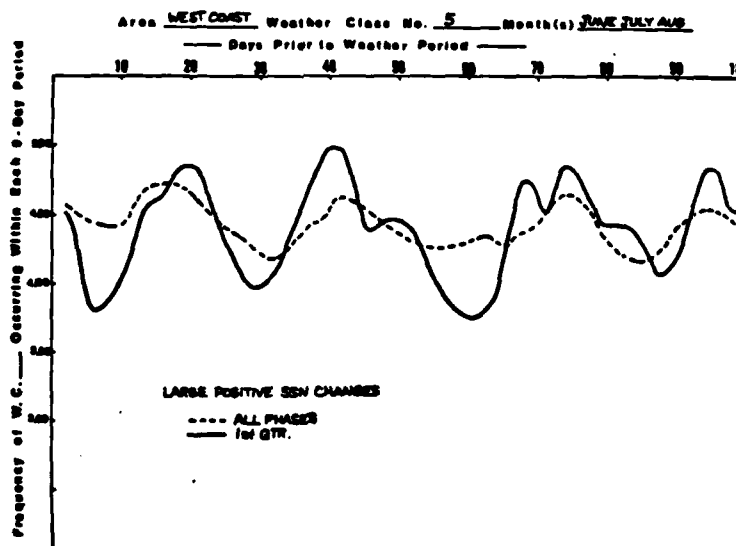


FIGURE 25. FREQUENCY OF OCCURRENCE OF WEATHER CLASS NO. 5 WHEN DSS VALUES WERE LARGE POSITIVE VALUES AND OCCURRED DURING THE 1st QUARTER OF THE SUMMER MONTHS.

These two charts are similar to Figures 24 & 25, except the timing is based upon the 3rd Quarter.

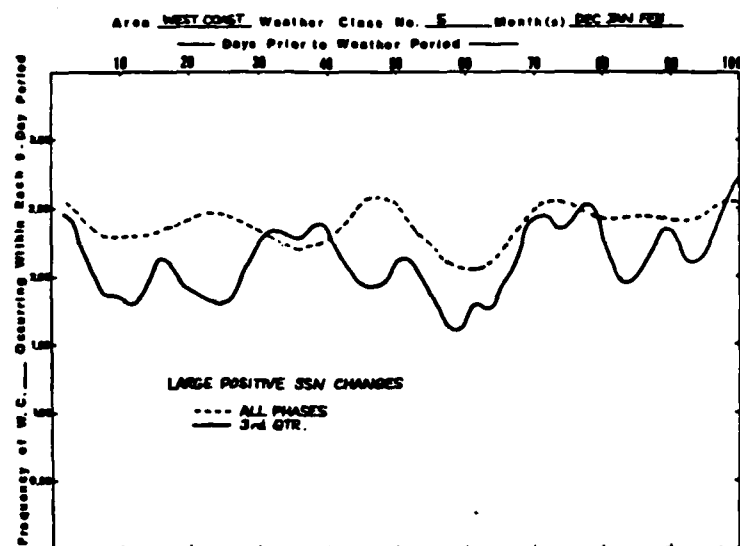


FIGURE 26. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 5, WHEN DSS VALUES WERE LARGE POSITIVE DURING THE 3rd QUARTER. -- WINTER.

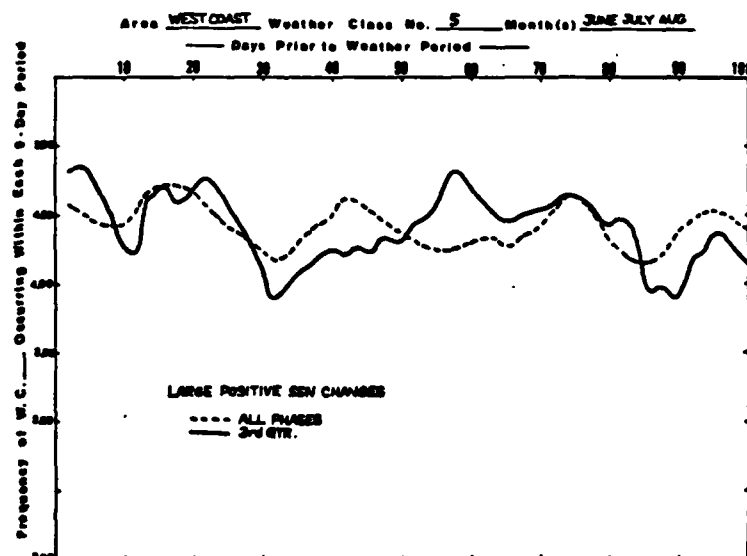


FIGURE 27. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 5, WHEN DSS VALUES WERE LARGE POSITIVE DURING THE 3rd QUARTER -- SUMMER.

These charts show the Frequency of Occurrence of Weather Class No. 4, during the winter months when large increases in SSN occur during the four phases of the lunar month.

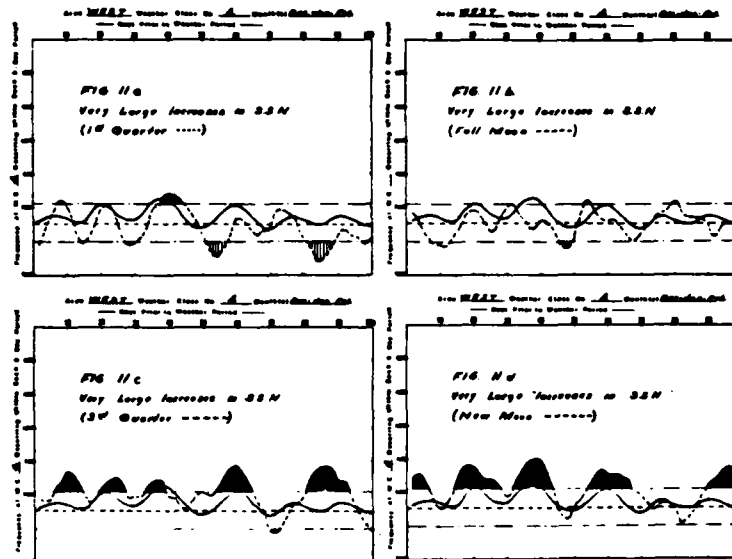


FIGURE 28. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4--WINTER MONTHS.

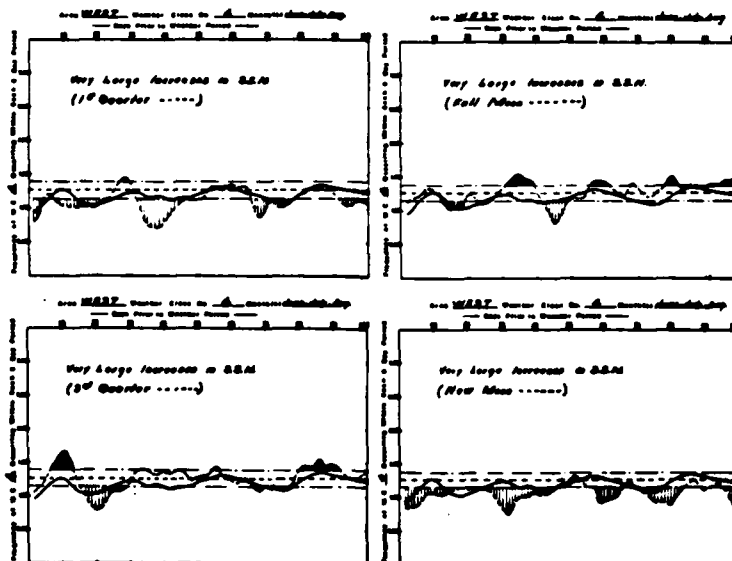


FIGURE 29. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 4 -- SUMMER MONTHS.

These charts show the Frequency of Occurrence of Weather Class No. 5 during the winter months and summer months when large increases in SSN occur during the four phases of the lunar month.

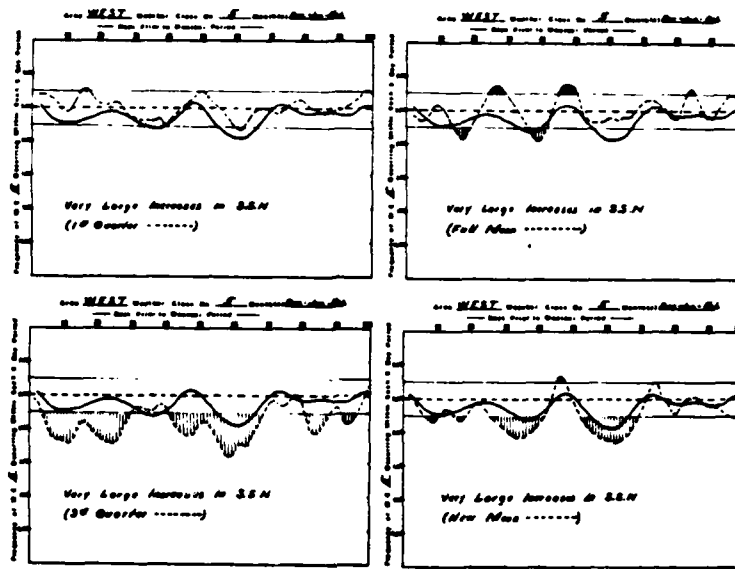


FIGURE 30. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 5 -- WINTER MONTHS.

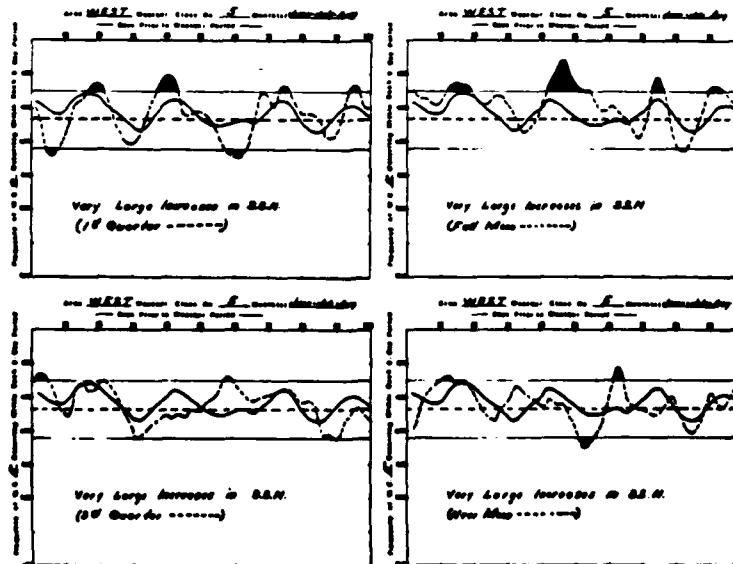


FIGURE 31. FREQUENCY OF OCCURRENCE OF WEATHER CLASS No. 5 -- SUMMER MONTHS.

Part of our investigation required analysis of the four phases of the sunspot cycle, i.e., what was the frequency of occurrence during the rising portion, the high portion, the falling portion, and the low portion of the 11-year sunspot cycle. These charts show the results obtained.

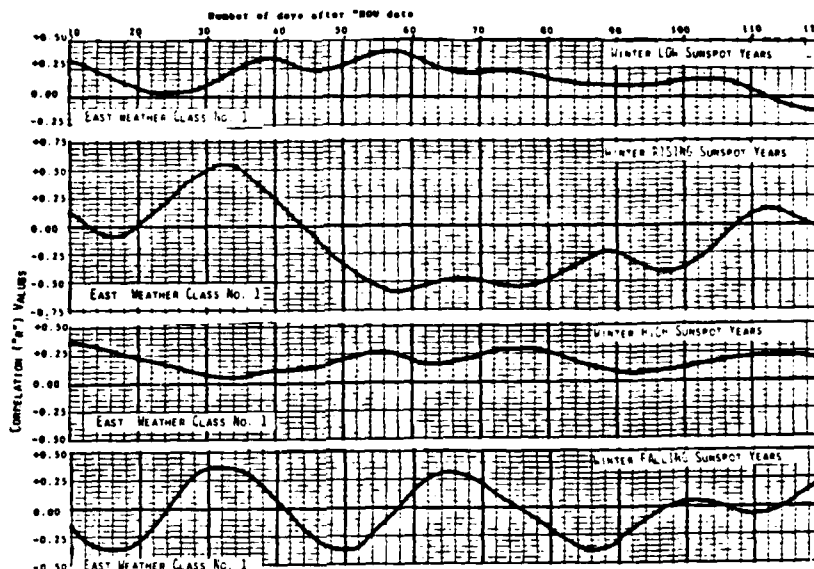


FIGURE 32. FREQUENCY OF OCCURENCE OF EAST COAST WEATHER CLASS NO. 1 FOR THE FOUR PORTIONS OF THE SUNSPOT CYCLE.

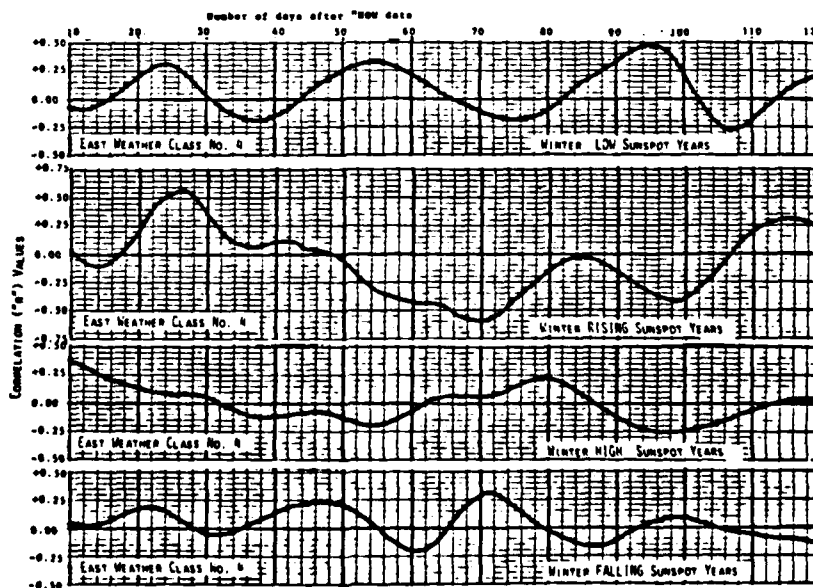


FIGURE 33. FREQUENCY OF OCCURENCE OF EAST COAST WEATHER CLASS No. 4 FOR THE FOUR PORTIONS OF THE SUNSPOT CYCLE.

These charts are similar to figures 32 & 33, except they are for the Central and West Coast regions. Attention is invited to the large fluctuations in the frequency of occurrence of Central Weather Class No 1 and No. 4 during RISING periods of sunspot numbers.

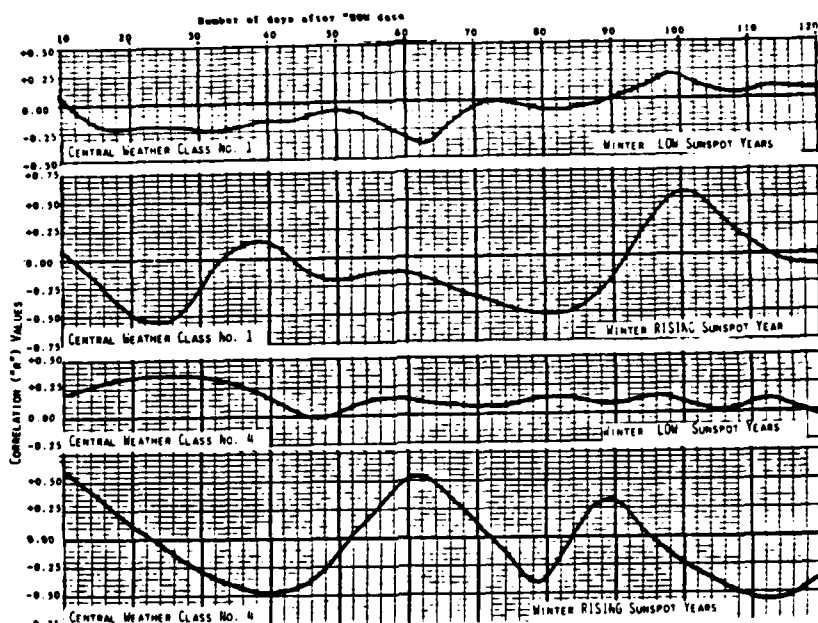


FIGURE 35. FREQUENCY OF OCCURRENCE OF CENTRAL WEATHER CLASS No. 1 & No. 4, DURING LOW AND RISING PERIODS OF SUNSPOT NUMBERS.

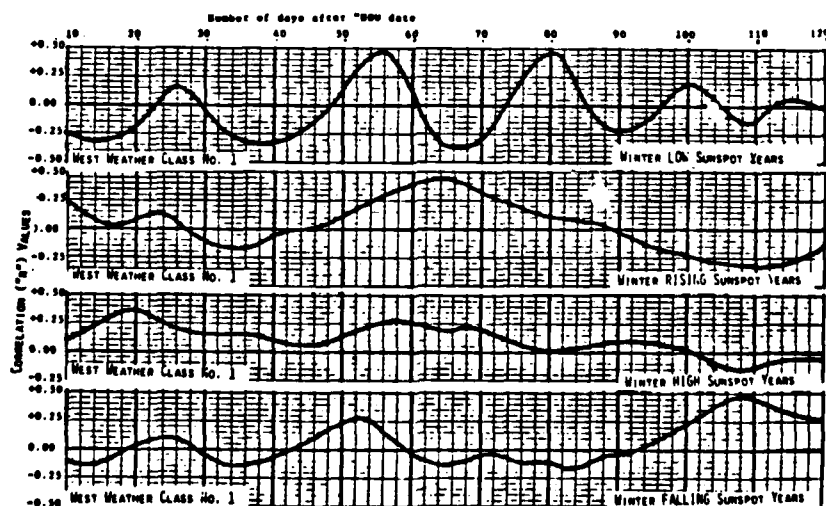


FIGURE 36. FREQUENCY OF OCCURRENCE OF WEST WEATHER CLASS NO.1, DURING LOW, RISING, HIGH, AND FALLING PERIODS OF SUNSPOT NUMBERS.

ACKNOWLEDGEMENTS

This work was supported in part by the Office of Naval Research under Contract N00014-77-C-0377, titled "Evaluation of Extended Period Forecasting Technique".

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SECTION III

PERSISTENT WEATHER REGIMES

By

Steven Anton Scherrer

PERSISTENT WEATHER REGIMES

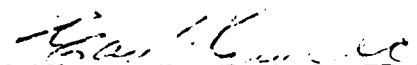
by
Steven Anton Scherrer
B.S. August 1978, Northern Illinois University
M.S. December 1981, Old Dominion University

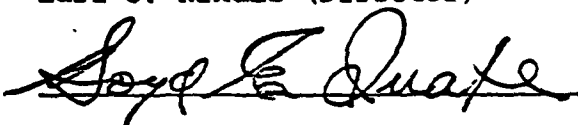
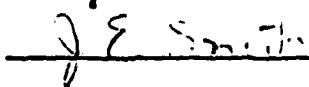
A Thesis Submitted to the Faculty of
Old Dominion University in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF SCIENCE
ATMOSPHERIC AND EARTH SCIENCE

OLD DOMINION UNIVERSITY
December 1981

Approved by:


Earl C. Kindle (Director)

ACKNOWLEDGMENTS

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ABSTRACT

PERSISTENT WEATHER REGIMES

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Old Dominion University, 1981
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Fifty years of surface temperature and precipitation data of three cities in Southeast Virginia were averaged to investigate persistent weather regimes. A composite average was used to eliminate singular weather events. Threshold values defining abnormal temperature and precipitation conditions were obtained from histograms of deviations from normal. These threshold values were used to examine characteristic lengths and properties of persistent regimes.

Using the threshold values, results showed that cold regimes during the winter season have a higher chance of persisting than warm regimes. Unfortunately, post analysis indicated that the arbitrary threshold temperatures which define this abnormal state were a little too severe and perhaps compromised these results. The onset and termination of persistent temperature regimes are very dependent upon the 500mb-level West Coast weather type.

Dry regimes have a higher chance of persisting than wet regimes. Precipitation deviations occur in 11-year cycles, suggesting a relationship with solar activity.

DEDICATION

I would like to dedicate this thesis to my father, whose dream was to send his children to college. Also to my mother, who struggled with me for years to prove I could succeed. To my wife, who helped me through the hardest times and kept pushing me onward. To my brother and sister, grandfathers and grandmothers, who all contributed to this thesis. And, finally, those associated with and working for the Atmospheric Science Department of Old Dominion University, the finest atmospheric science program in the country.

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I. INTRODUCTION

Statement of the Problem

During the past several abnormal winters and particularly during the drought of 1980, there has been an increased interest in persistent weather regimes, especially by service-oriented public utilities that are sensitive to these long-term weather regimes. This strongly indicates a definite need for new extended weather forecasting techniques to predict the occurrence of these persistent regimes above or below their norm. Presently, specific forecasting methods for predicting onset or termination of these persistent regimes are limited.

Literature Review

It's long been known that there is a tendency for weather to be serially correlated. Bonacina (1965) examined the dependence of weather on the past and concluded that excesses of weather of one kind or another repeat themselves in the same geographical region even though there may be a complete reversal of weather type. Bonacina suggests that if these situations in which a dependence factor is obvious can be detected, they could be used for long-range forecasting.

Wright (1977) examined persistent weather patterns and found that positive feedback mechanisms play a critical role in many anomalies. Wright suggests that regions where persistent anomalies often occur should be monitored to identify occasions when positive feedback is likely to favor persistence of any anomaly which develops.

Craddock (1963) examined persistent temperature regimes by using five-day mean temperature anomalies observed in England from 1901 to 1961. He found some evidence that patterns in the sequence of temperature anomalies may sometimes extend to 30 days, but there was not any evidence these patterns would continue any longer. Craddock concludes that the tendency for temperature regimes to persist is weak in spring and autumn, and stronger in winter and summer, being strongest of all in late summer. Dyer (1978) studied the intercorrelations between monthly mean temperatures for central England from 1874-1973 within one and within two years and between each month and its preceding one. He concluded that persistence is favored during the months of March, August and September, while months with poor persistence were May, June, October, November, and December. Little information was carried over from one year to the next.

Gordon and Wells (1976) rated the anomalies from the respective decadal means of the monthly mean temperatures for central England for a 250-year period to form a quintile distribution. Contingency tables were prepared showing the percentage frequencies of the changes in the temperature

anomalies from one calendar month to the next calendar month for each quintile. They observed that persistence of anomalies of monthly mean temperatures from one month to the next is highly significant for the extreme quintiles. Very cold months appear slightly more persistent than very warm months. The persistence of extreme anomalies at certain times of the year were double the frequency expected by chance, while the changes from one extreme quintile to the other occur with very low frequency as compared with chance.

Dickson (1967) studied the relationship between mean temperatures of successive months in the U. S. for 60 years of data. He found the data to be of a persistent nature, with maximum persistence occurring in the mid-nation during the summer with secondary maximum found in the West from April to May and in the East from December to January. He observed that persistence is of local origin arising from the anomalous thermal state of the earth's surface. Month-to-month temperature persistence was found to be independent of long-term temperature trends and of relationships between the temperatures of a given month in adjacent years. Regions of month-to-month persistence were found to correspond broadly to areas of maximum secular temperature fluctuations. Dickson concluded that the basic mechanisms responsible for secular temperature fluctuations and month-to-month temperature persistence are essentially the same.

Namias (1952) examined month-to-month persistence in anomalies of temperature, precipitation and mid-tropospheric

flow during all adjacent pairs of months for 200 U. S. cities (excluding April to May and October to November when abrupt transition of long period regimes occur). Namias' examination of persistent weather regimes suggested possible gradual secular trends, though data covered only 18 years. Later, Namias (1978) examined the persistence of U. S. seasonal temperatures up to one year at 200 stations in the U. S. for 40 years of data. Namias found that seasonal persistence is most pronounced 1) when summer is antecedent, 2) in most seasons along the West and East coasts and near the Great Lakes, and 3) in areas and times where and when variability of snow cover or antecedent precipitation is large. Namias concluded that physical concepts involving heat storage and teleconnections from large-scale coupled air-sea systems over the North Pacific are the causes, though the correlations were too small to be of any predictive value.

While the use of monthly values defines most persistent regimes, a monthly value need not be indicative of the monthly weather. An abnormal period of weather of a few days' length could cause a month to be classified as being abnormal, though the majority of the month was normal. This study examines day-to-day persistence and although not offering specific techniques for prediction of these regimes, it does examine their probability of continuation and considers possible extra-terrestrial causes.

II. APPROACH

Temperature Study

Fifty years of daily surface observations of temperature were used to search for characteristic length of anomalous persistent weather regimes over southeastern Virginia. To minimize the effects of single events, a composite average of three cities was computed to obtain a regional daily average temperature, thereby reducing orographic and oceanic effects. The daily average temperature values obtained at three stations in southeast Virginia (Norfolk, Richmond and Danville) were averaged to provide a single value of the regional daily average temperature. The temperature study was conducted on 49 winter seasons from 1930-31 to 1978-79. Each winter season was composed of a 160-day period beginning on October 12 and ending on March 20 (March 19 in leap year). A daily normal temperature was computed for each day of the 160-day seasonal sequence by computing a 49-year average of the regional daily average temperature. Deviations from these normal temperatures were computed for all 49 winter seasons and stored on a computer disk for subsequent data analysis and interpretation.

III. ANALYSIS OF ANOMALOUS TEMPERATURE REGIMES

Characteristic Lengths of Temperature Regimes

A histogram and cumulative histogram of the daily temperature deviations for the 49 winter seasons were graphed in order to select an arbitrary critical magnitude of temperature deviation which would define abnormal conditions. These threshold values had to satisfy the following conditions:

- 1) The threshold values were large enough to select a significant weather event.

- 2) The threshold values had to be small enough to ensure adequate population for statistical purposes.

Figures 1 and 2 are the histogram and cumulative histogram, respectively, of daily temperature deviations. Threshold values of plus or minus four degrees Fahrenheit from the daily normal temperatures were qualitatively judged to fit the two criteria satisfactorily. Each of the abnormal populations contain approximately 32 percent of the daily temperature deviations.

The sequential temperature deviations were then scanned for each winter season using the threshold values to obtain a frequency diagram of the temporal lengths of cold and warm temperature regimes. Figure 3 is a frequency diagram

of the lengths of the cold (dashed line) and warm (solid line) regimes of the 49 winter seasons. Their distribution is very similar, showing very few regimes lasting longer than ten days. While there were a few more warm than cold regimes of eight to 12 days' length, more cold regimes persisted longer than 12 days.

Persistence Probabilities of Temperature Regimes

Probability studies were conducted to determine the likelihood of continuation of cold and warm regimes. Figure 4 shows the probability of continuation of a warm regime. The ordinate represents the probability of continuation of a warm regime, while the abscissa represents the length of a warm regime. Each curve represents a separate probability study, with N being the initial condition of the number of warm days that already have occurred in sequence. For example, from Figure 4 it can be seen that the probability of a one-day warm regime continuing to two days is .67, to three days is .40, to four days is .26, etc. The dashed line is the probability of occurrence of specific length warm regimes without any initial conditions (i.e., the climatological probability). The dotted line linearly connects the distinct probability studies to examine the day-to-day probabilities of increased persistence after a specific sequence of warm days. The important aspects of these probability curves are that once any sequence of warm days occurs,

there is at least a 60 to 65 percent chance of a warm regime persisting for another day, but the chance of the next two days being warm decreases to 40 percent. Also, if a warm day has already occurred, the chance of the warm regime persisting is 10 to 50 percent higher than the climatological probability.

In summary, warm regimes will have a significantly higher chance of persisting for the next succeeding two days if any sequence of warm days has occurred, but the chance of persisting three or more days is less than 25 percent. There is a slight increase in persistence from four to five days, but the overall day-to-day probabilities are constant.

The likelihood of continuation of a cold regime was investigated and is shown in Figure 5. The diagram is defined in the same manner as Figure 4, with the ordinate representing the probability of continuation of a cold regime and the abscissa representing the length of cold regimes. The dotted line again linearly connects the distinct probability studies to investigate the possibility of increased persistence after a specific sequence of cold days. After a sequence of six or seven cold days, there is increased persistence, especially if a week of cold weather has occurred (65 percent chance of persisting to an eighth day and a 60 percent chance of persisting to a ninth day). Whether the increase in persistence would last past nine days was not handled in this study due to the limited amount of cases continuing past nine days.

In summary, a cold regime lasting from one to seven days has at least a 60 percent chance of persisting for another day, at least a 40 percent chance of persisting for another two days, and at least a 30 percent chance of persisting for another three days. If a sequence of six or more days occurs, there is a significantly higher chance of persistence. When comparing warm and cold regime continuation probabilities, there is an increased chance of a cold regime persisting, especially after a sequence of seven days.

Investigation of the Temperature Trend

The temperature trend of the winter seasons from 1930-31 to 1978-79 was examined by computing an average daily temperature deviation for each winter season of 160 days. Figure 6 shows the winter seasons (abscissa) plotted against the average daily temperature deviation of each 160-day winter season (ordinate). Relatively normal to above normal temperatures occurred from 1930 until 1958. A cooling trend occurred from 1958 until 1970. A warm period occurred during the early 1970s, followed by a return to below normal temperatures.

Investigation of Using a Seven-day Running Mean

In order to smooth-out single weather events, a seven-day running mean centered on the fourth day was performed on the daily temperature deviations. Figures 7 and 8 show a histogram and cumulative histogram, respectively, of the seven-day running means of the sequential daily temperature deviations of all 49 winter seasons. Optimum threshold values defining abnormal conditions were chosen from these histograms in a manner analogous to the method used earlier employing Figures 1 and 2. Threshold values which satisfied earlier stated criteria were determined to be plus or minus four degrees above and below normal, indicating that each of the abnormal populations contain 26 percent of the temperature deviations.

The seven-day running means of the sequential daily temperature deviations were scanned for each winter season using the threshold values to obtain a frequency diagram (Figure 9) of the temporal lengths of cold (dashed line) and warm (solid line) regimes for all 49 winter seasons. Their distributions are very similar. However, there is a unique point at the four-day mark due to some unknown statistical problem. Further investigations using a seven-day running mean were terminated after attempts to rectify this problem failed.

Extending Regime Length by Including Short Breaks

The comprehensive portrayal of the whole winter season for each year is shown in Figure 10. Each day of the 160-day winter seasons was classified according to the threshold values for warm (four or more degrees Fahrenheit above normal), cold (four or more degrees Fahrenheit below normal), and normal (more than four degrees Fahrenheit below normal and less than four degrees Fahrenheit above normal). Figure 10 shows the cold (dashed line), warm (solid line) and normal days of the winter seasons. The abscissa represents the winter seasons spanning from 1930-1979, while the ordinate represents the 160-day winter seasonal sequence beginning October 12 and ending March 20 (ending March 19 in seasons with leap year).

The breaks of normal temperatures could be perceived to be part of the randomly occurring regimes, especially if interspersed between two randomly occurring cold or warm regimes. As discussed earlier, very few continuous regimes extended longer than ten days. In order to enhance regime length, the inclusion of the short breaks was a necessity. Arbitrary criteria were developed that permitted limited breaks within a given cold or warm period. These criteria were:

- 1) At least 75 percent of all the days of a regime must be cold or warm.
- 2) Only one day of cold weather could occur during a

warm regime.

3) Only one day of warm weather could occur during a cold regime.

Figure 11 is a frequency diagram of the temporal length of these newly defined regimes. The number of cold and warm regimes lasting anywhere from four to ten days were essentially equal. While there were more warm than cold regimes of ten to 14 days' length, more cold regimes persisted longer than 14 days. In comparing the distributions of the length of regimes with (Figure 11) and without (Figure 3) breaks, the number of regimes of six to 13 days' length increased significantly when the breaks were utilized.

Some probability studies were conducted on the regimes utilizing breaks and the results were:

1) The average return period for warm regimes in the winter season persisting more than 20 days was 3.5 years.

2) The average return period for cold regimes in the winter season persisting more than 21 days was 2.6 years.

3) If a cold regime lasting ten days or more occurred in a winter season, the chance of another one occurring was 42 percent. If a warm regime lasting ten or more days occurred in a winter season, the chance of another one occurring was 59 percent.

The persistence of longer regimes was examined by using the regimes with short breaks. A cumulative probability diagram of the chance of an 11-day warm or cold regime

persisting 11 days or longer was computed and is shown in Figure 12. The abscissa is the different categories of regime length plotted against the cumulative probability of an 11-day regime persisting to that category of regime length or longer. For example, the probability of an 11-day warm regime persisting to 18 days or longer was .20. Some observations from Figure 12 are:

- 1) There was at least a 50 percent chance of an 11-day cold or warm regime persisting to 15 days or longer.

- 2) There was a 20 percent chance of an 11-day cold and a 15 percent chance of an 11-day warm regime persisting to 20 days or longer.

- 3) There was a 10 percent chance of an 11-day cold and a 2 percent chance of an 11-day warm regime persisting to 30 days or longer.

In summary, it is rare for an 11-day cold or warm regime persisting to 20 days or longer, half of them terminate before 15 days. The 11-day cold regimes have a higher chance of persisting than the 11-day warm regimes in the winter season, as discovered previously.

500mb-Level Correlations with Temperature Regimes.

A study was conducted to investigate the influence of upper air patterns on the onset and termination of surface regimes. Also, the processes in the upper air pattern enabling a temperature regime to persist were examined.

In order to study the upper air pattern quantitatively, data were obtained from Quate and Wobus (1976) of the daily weather classification for the West Coast, East Coast, and central portions of the continental U. S. at the standard 500mb level. Each geographical region was classified for each day of the period from 1946-1976 as being influenced by a pressure ridge, pressure trough, or neither. The normal climatic number of ridge and trough occurrences for a ten-day period was computed for each of the winter months by computing an average of 30 years (1946-1976) of data for each of the three geographical regions. Cumulative deviations from the normal climatic number of ridge and trough occurrences for a ten-day period were summed for a period of ten days before a regime, during a regime, during the last seven days of a regime, and a period of ten days after a regime for each of the three geographical regions.

A diagram was constructed showing the cumulative deviations from the ten-day period climatic normals of trough and ridge occurrence for each of the three geographical regions for a period of ten days before a regime, during a regime, during the last seven days of a regime, and a period of ten days after a regime.

Figure 13 shows this diagram for ten-day warm regimes. The importance of a West Coast trough in determining onset of a warm regime in Southeast Virginia is clearly shown. Once the warm regime begins, a significant ridge occurs on the East Coast which is being caused by warm air advection

from the West Coast trough. Once the West Coast trough weakens, the regime will begin to break up and eventually terminate as the West Coast trough and East Coast ridge dissipate.

Figure 14 shows the 20-day warm regime cumulative deviations of trough and ridge occurrence for a ten-day period and again shows the significance of a trough occurring on the West Coast as a determining factor in warm regime onset and termination. Warm regimes will persist as long as West Coast troughing continues, but will terminate shortly after the West Coast trough dissipates.

Figure 15 shows the ten-day cold regime cumulative deviations of trough and ridge occurrence for a ten-day period. The onset of a ten-day cold regime is caused by a Central U. S. trough advecting eastward. Slight West Coast and Central U. S. ridging occur during the cold regime, while a trough persists on the East Coast. The ten-day cold regimes terminate as the East Coast trough advects eastward and ridging terminates in the Central U. S. and on the West Coast.

Figure 16 shows the 20-day cold regime cumulative deviations of trough and ridge occurrence for a ten-day period. The onset of a 20-day cold regime occurs as a complete reversal of the West Coast flow pattern changes from a trough (before the regime) to a ridge (during the regime). Troughing occurs in the Central and Eastern U. S. during the first ten days of a 20-day cold regime. Once

the West Coast ridge dissipates, the 20-day cold regime terminates. The ten-day cold regimes occur as a Central U. S. trough moves eastward and terminates as the trough continued moving eastward, while a 20-day cold regime is associated with strong ridging on the West Coast and Central and Eastern U. S. troughing.

The dependence of persistence of cold and warm regimes in Southeast Virginia on the weather type on the West Coast in the winter seasons is clearly indicated in this study. This supports Namias' view of persistent weather regimes in the U. S. being dependent on the ocean temperatures of the Pacific Ocean.

IV. PRECIPITATION ANALYSIS

Precipitation Scheme

Fifty years of daily surface observations of precipitation amount were examined with a method analogous to the temperature method previously employed. Since precipitation occurs sporadically, a daily average precipitation amount for each five-day period of each year (73 five-day periods per year) was computed for the three cities of Norfolk, Richmond and Danville. To minimize singular precipitation events, a composite average of the three cities was computed to obtain a regional daily average precipitation amount for five-day periods, thereby reducing orographic and oceanic effects. As in the temperature study, a daily normal precipitation amount was computed for each five-day period of a year (73 in all) by computing a 50-year average of the regional daily average precipitation amount. Deviations from these normal precipitation amounts were computed for all 50 years and stored on a computer disk for subsequent data analysis and interpretation.

V. ANALYSIS OF ANOMALOUS PRECIPITATION REGIMES

Characteristic Lengths of Precipitation Regimes

A histogram of the daily average precipitation deviations of the five-day periods for all 50 years of data were graphed in order to determine the magnitude of precipitation deviation which represents abnormal conditions. Figure 17 is a histogram of the daily average precipitation deviations for five-day periods. The maximum number of occurrences at $-.10$ inches is due to the large number of five-day periods in which precipitation does not occur. Due to the skewness of Figure 17, the daily precipitation amount deviations were normalized (observed-average/average).

A histogram and cumulative histogram of the normalized daily precipitation deviations for five-day periods were graphed and are shown in Figures 18 and 19, respectively. Threshold precipitation deviation values which define abnormal conditions were obtained from these histograms. These threshold values had to satisfy the earlier stated criteria used in the temperature study. A dry normalized daily average precipitation deviation amount for a five-day period was defined to be $-.50$ or less (50 percent or below normal precipitation), while a wet five-day period was $.25$ or more (25 percent or above normal precipitation).

Although the population of the five-day dry periods contained 50 percent of all the cases (Figure 21), it was considered acceptable due to the sporadic nature of precipitation occurrence.

The sequential normalized precipitation deviations for five-day periods were then scanned for each year using the threshold values to obtain a frequency diagram of the temporal lengths of dry and wet regimes. Figure 20 is a frequency diagram of the lengths of the dry (solid line) and wet (dashed line) regimes of the 50 years of data. There are more wet than dry regimes of five days' length occurring, but more dry regimes persist past ten days. Almost all of the dry and wet regimes terminate before 30 days, perhaps due to large scale circulation pattern changes at 28-day intervals.

Persistence Probabilities of Precipitation Regimes

Probability studies were conducted to determine the likelihood of continuation of dry and wet regimes. Figure 21 shows the probability of a dry regime. The ordinate represents the probability of continuation of a dry regime, while the abscissa represents the length of a dry regime. As in the temperature study, each curve represents a separate probability study, with N being the initial condition of how many dry five-day periods have already occurred in sequence. The dashed line represents the climatological

probability, while the dotted line linearly connects the distinct probability studies to examine the period-to-period probabilities in order to investigate increased persistence after a specific sequence of dry periods. The only significant increase observed of the period-to-period probabilities occurred after a sequence of 20 days. Also, if a dry period has already occurred, the chance of the dry regime persisting is five to 35 percent higher than the climatological probability. Once any sequence of dry periods has occurred, the chance of the dry regime persisting for another five days is at least 45 percent, but the chance of persisting another ten (20 percent) or 15 (10 percent) days are much less.

In summary, dry regimes will have a significantly higher chance of persisting for the next five-day period, but the chance of persisting ten days or more is less than 20 percent. The increase in persistence following 20 days of dry weather is unique and probably can be attributed to atmospheric circulation cycles.

The probabilities of the likelihood of continuation of a wet regime were investigated and are shown in Figure 22. The diagram is defined in the same manner as Figure 21, with the ordinate representing the probability of continuation of a wet regime and the abscissa representing the length of a wet regime. The dotted line again linearly connects the distinct probability studies to investigate increased persistence after a specific sequence of five-day periods. The

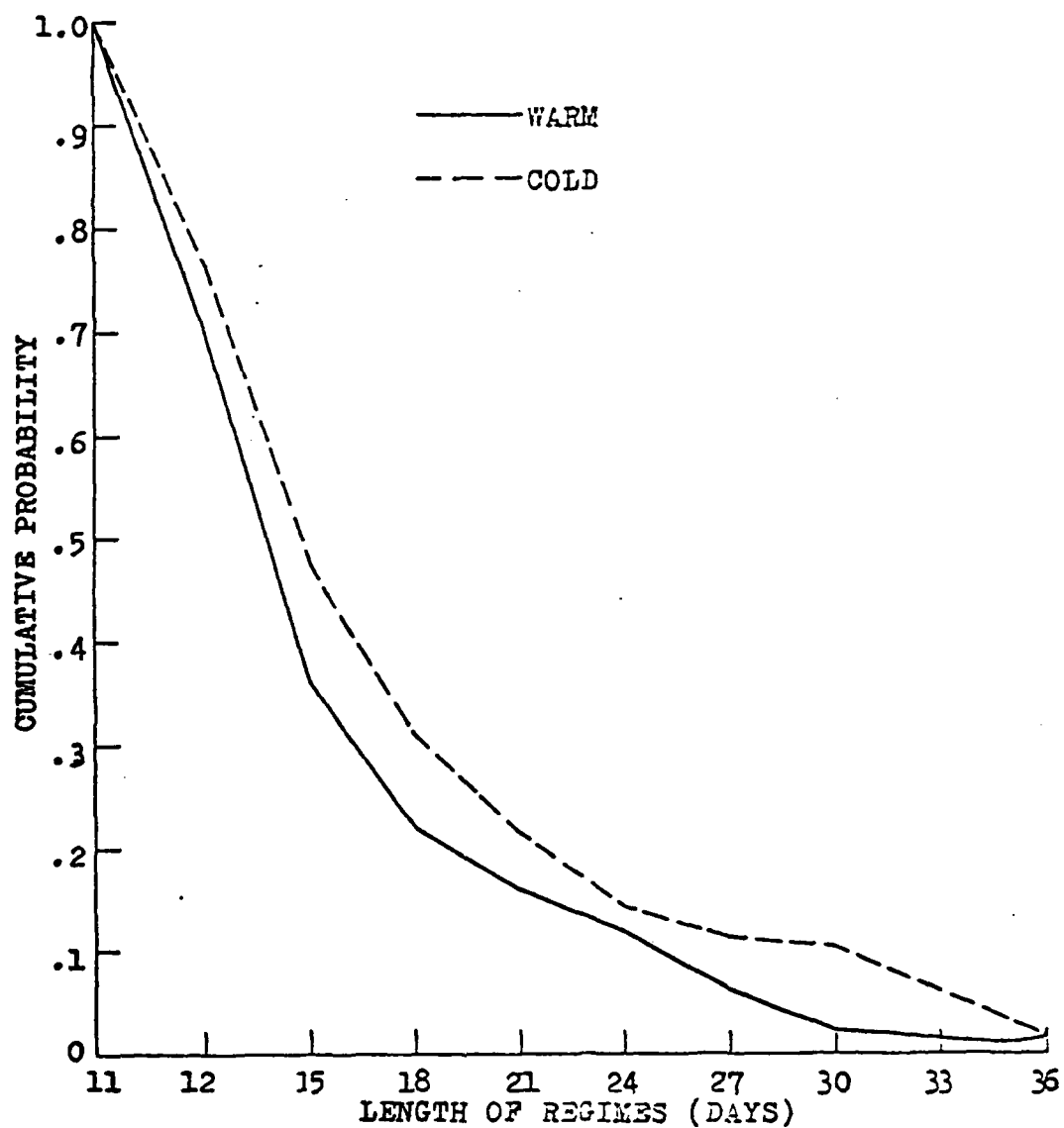


Figure 12. Cumulative probability of regime continuation for an 11-day warm (solid line) or cold (dashed line) regimes with short breaks.

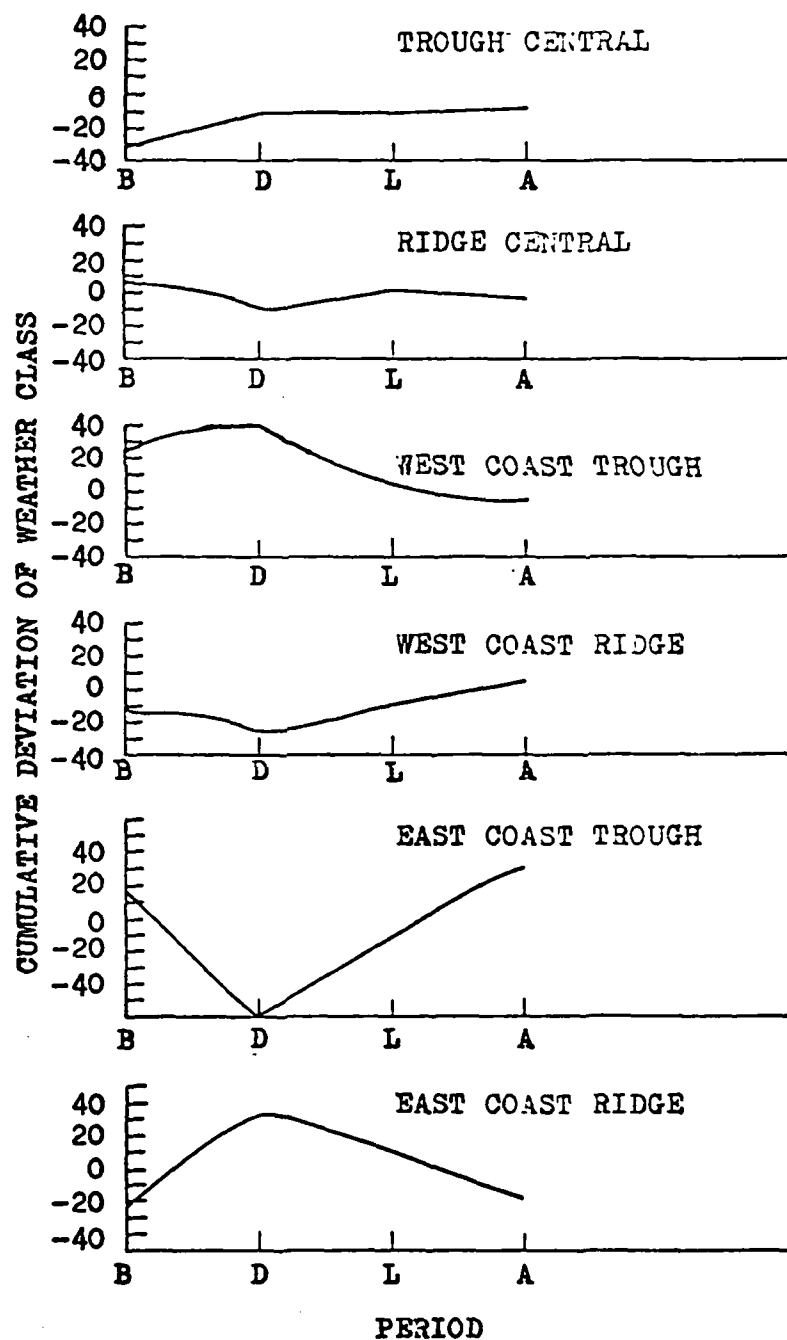


Fig. 13. Cumulative deviation of weather class for three geographical regions of the U.S. for ten-day periods before (B), during (D), during the last seven days (L), and after (A) a ten-day warm regime.

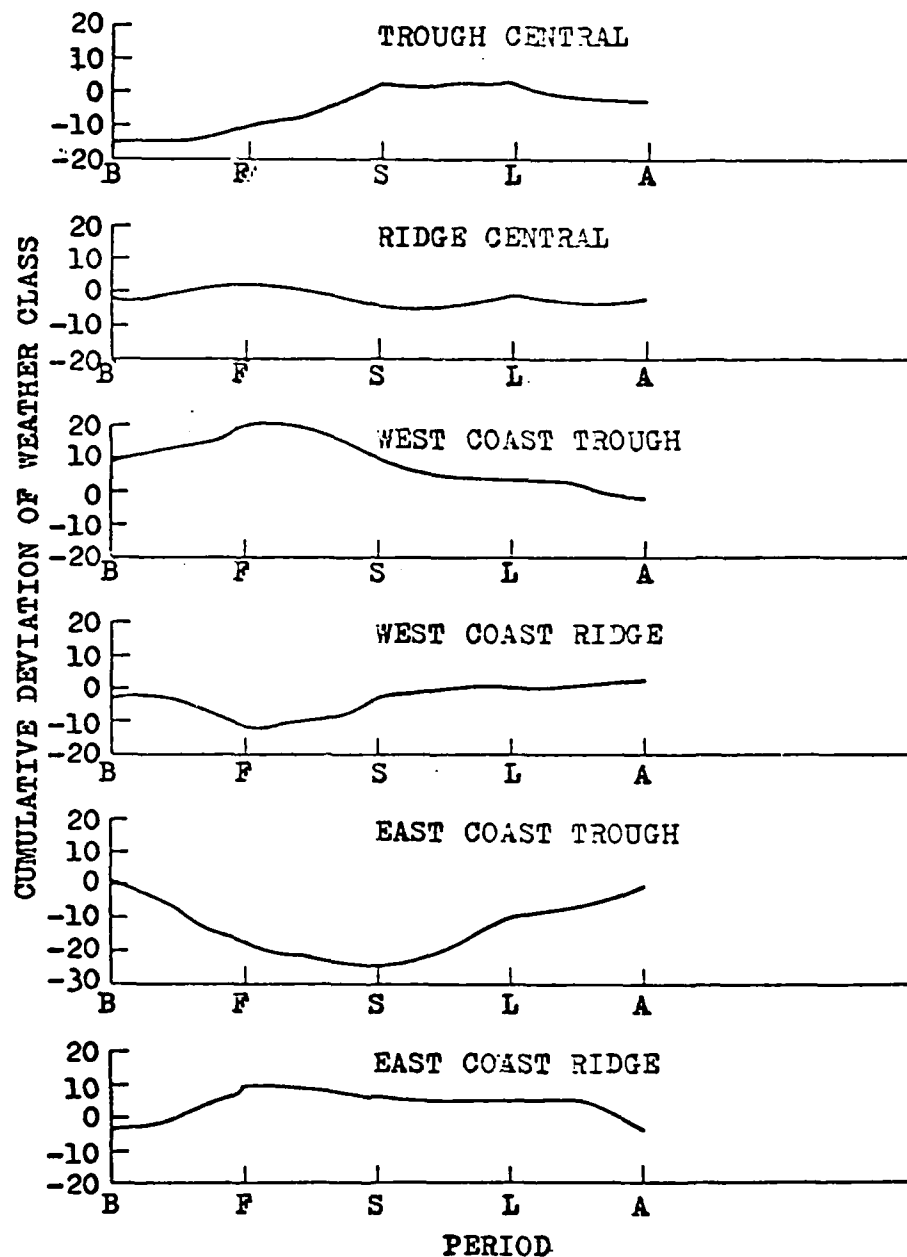


Fig. 14. Cumulative deviation of weather class for three geographical regions of the U.S. for 10-day periods before (B), first ten days (F), second ten days (S), during the last seven days (L), and after a 20-day warm regime.

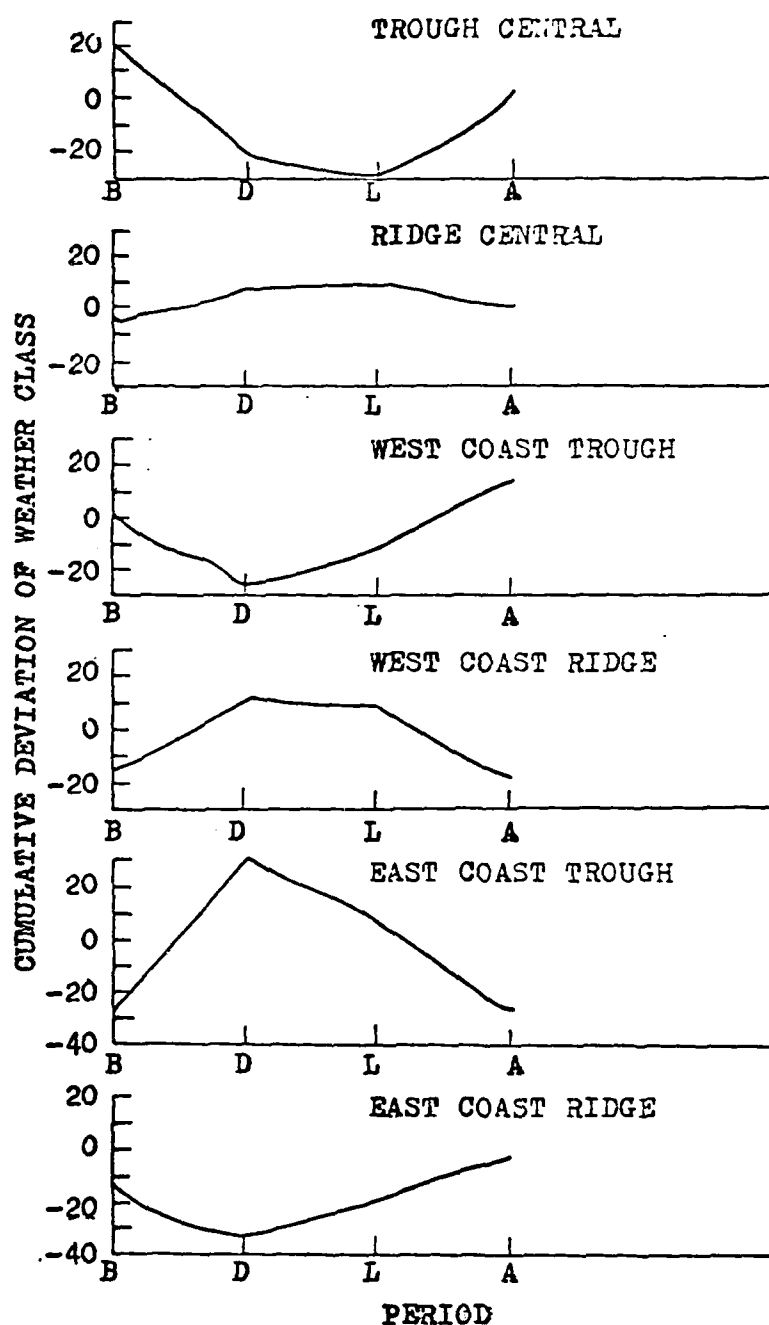


Fig. 15. Cumulative deviation of weather class for three geographical regions of the U.S. for ten-day periods before (B), during (D), during the last seven days (L) and after (A) a ten-day cold regime.

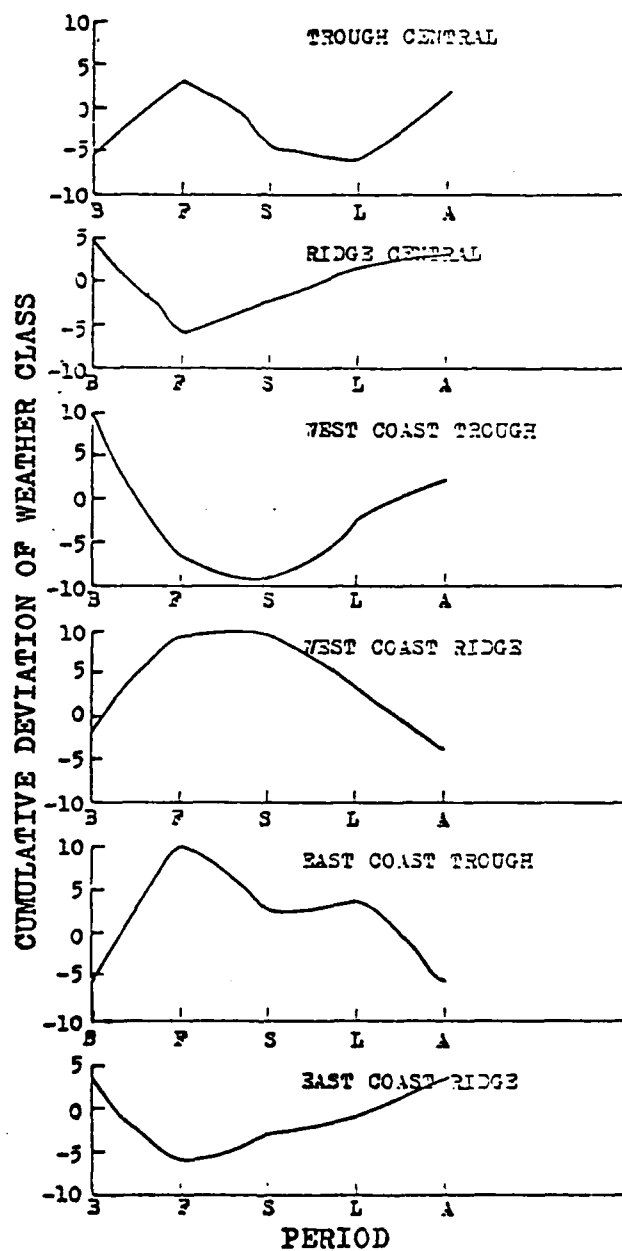


Fig. 16. Cumulative deviation of weather class for three geographical regions of the U.S. for ten-day periods before (B), first ten days (F), second ten days (S), during the last seven days (L), and after (A) a 20-day cold regime.

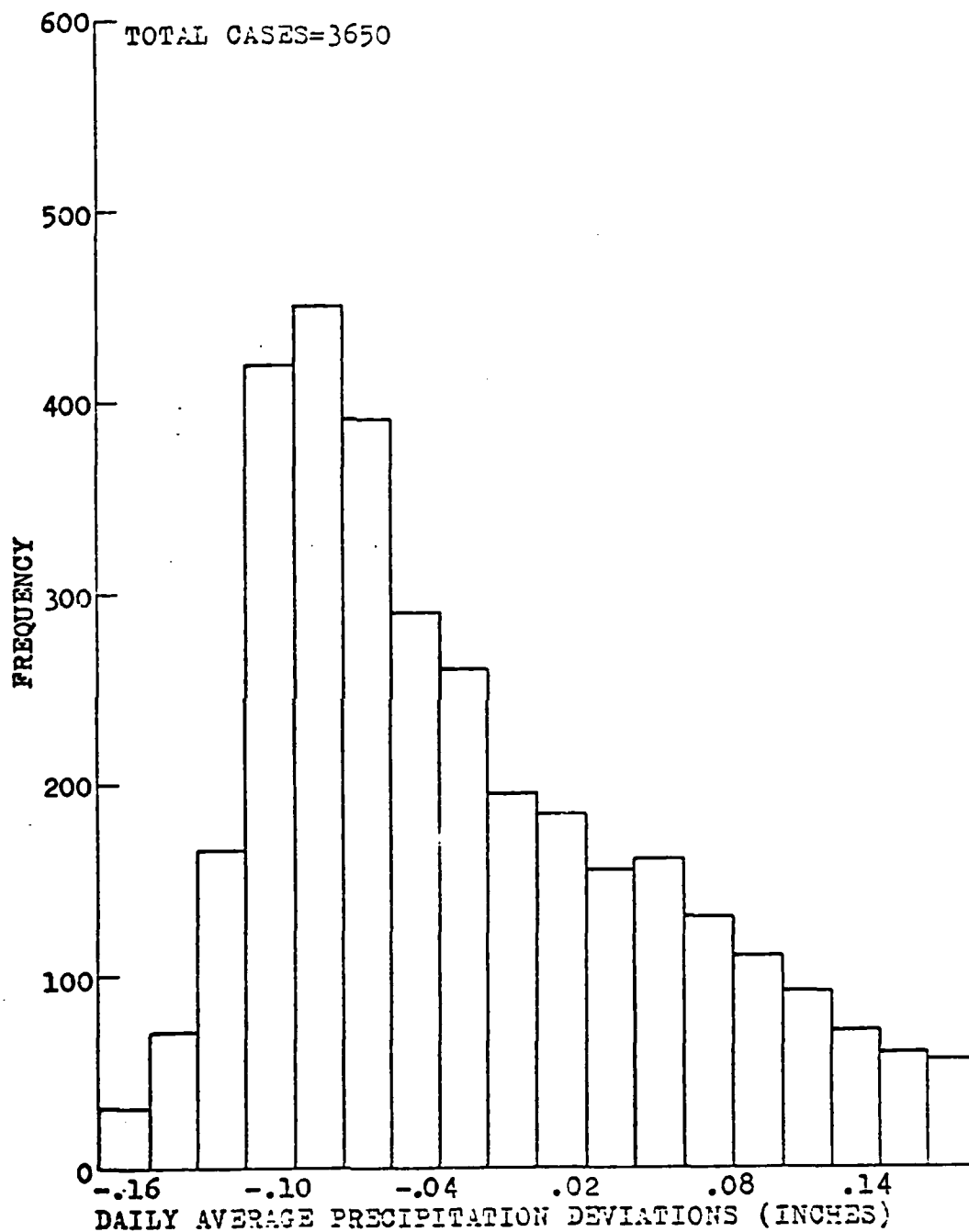


Figure 17. Histogram of the daily average precipitation deviations for five-day periods for the period 1930-1979.

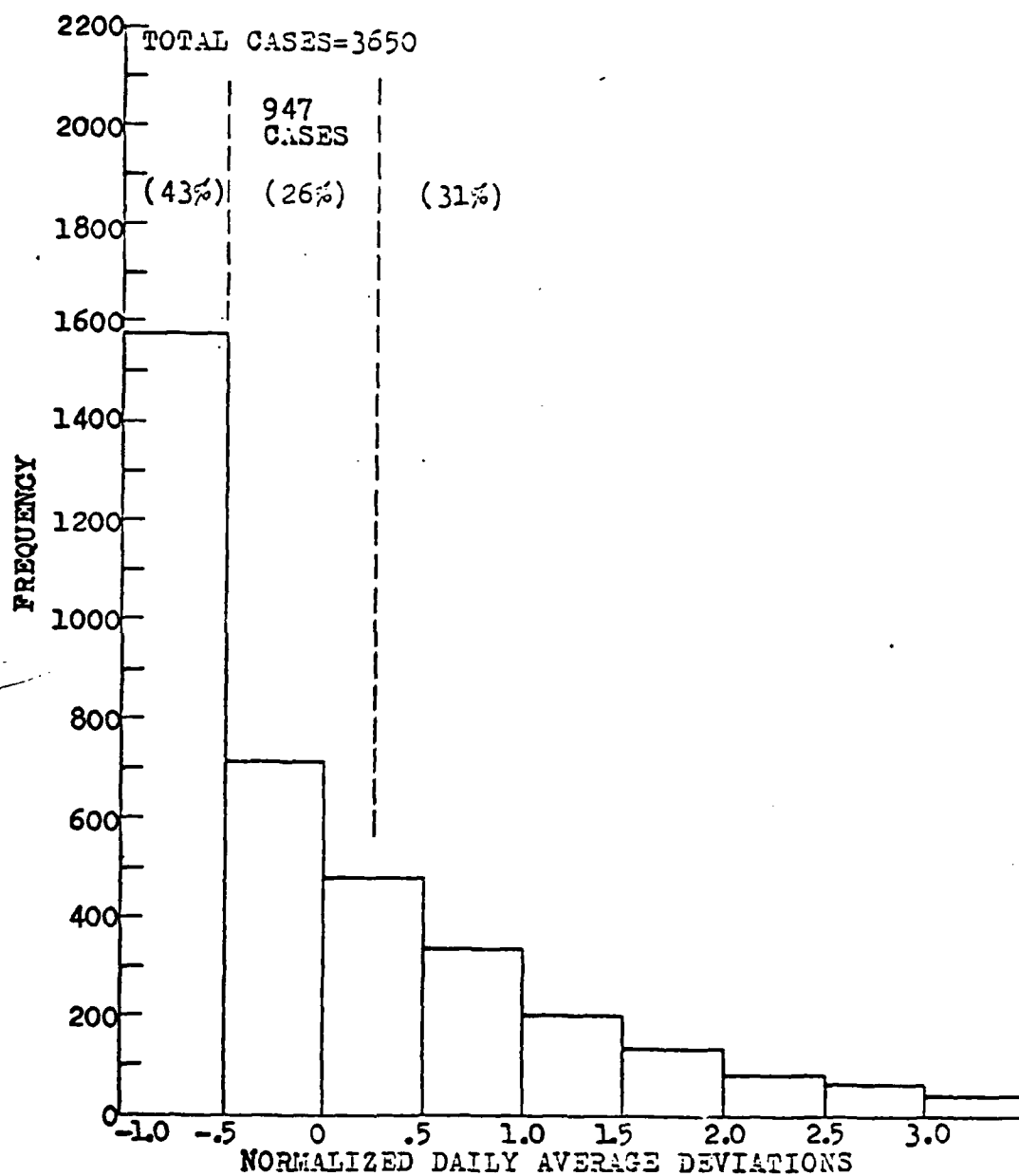


Figure 18. Histogram of the normalized daily average precipitation deviations for five-day periods for the period 1930-1979.

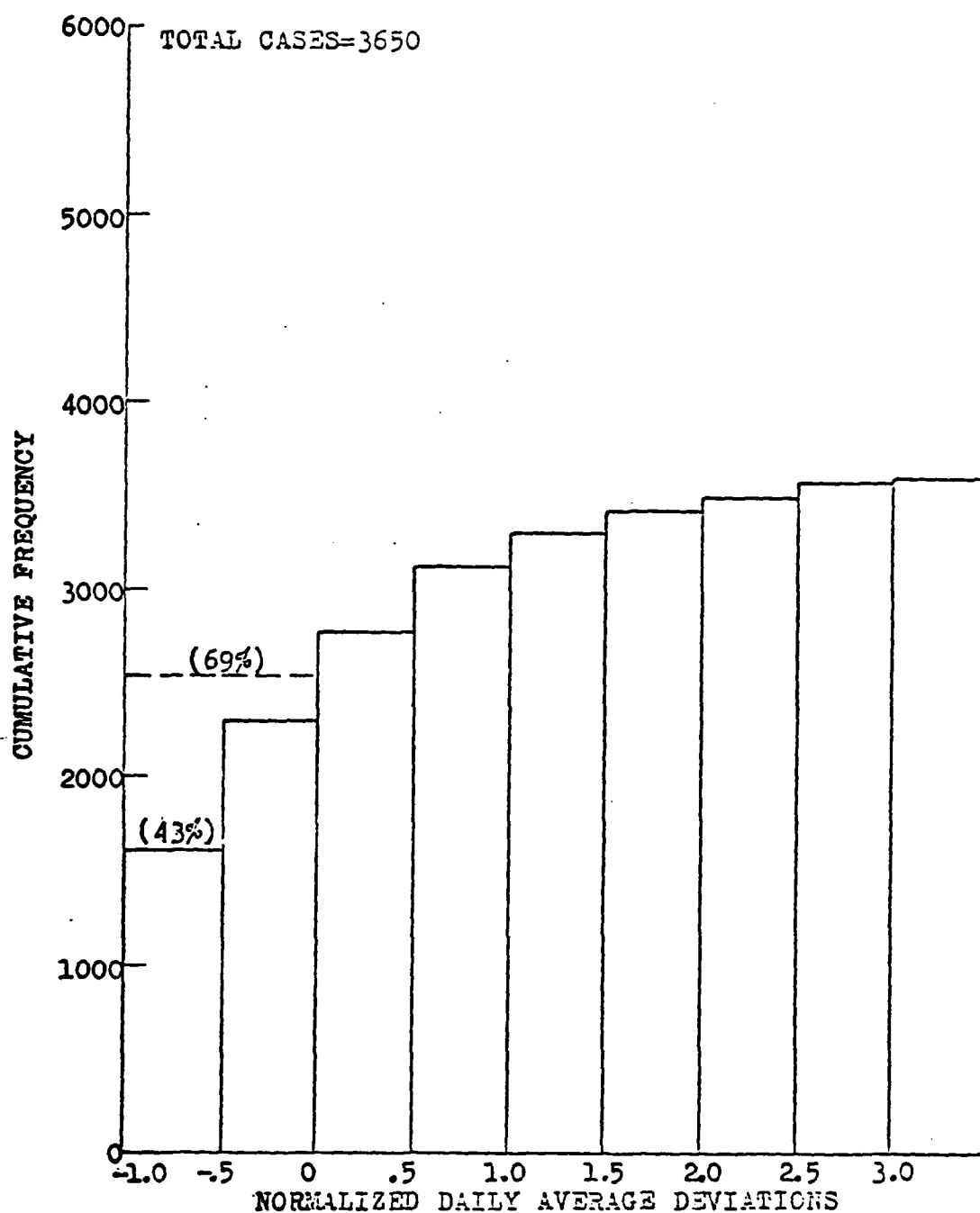


Figure 19. Cumulative histogram of the normalized daily average precipitation deviations for five-day periods for the period 1930-1979.

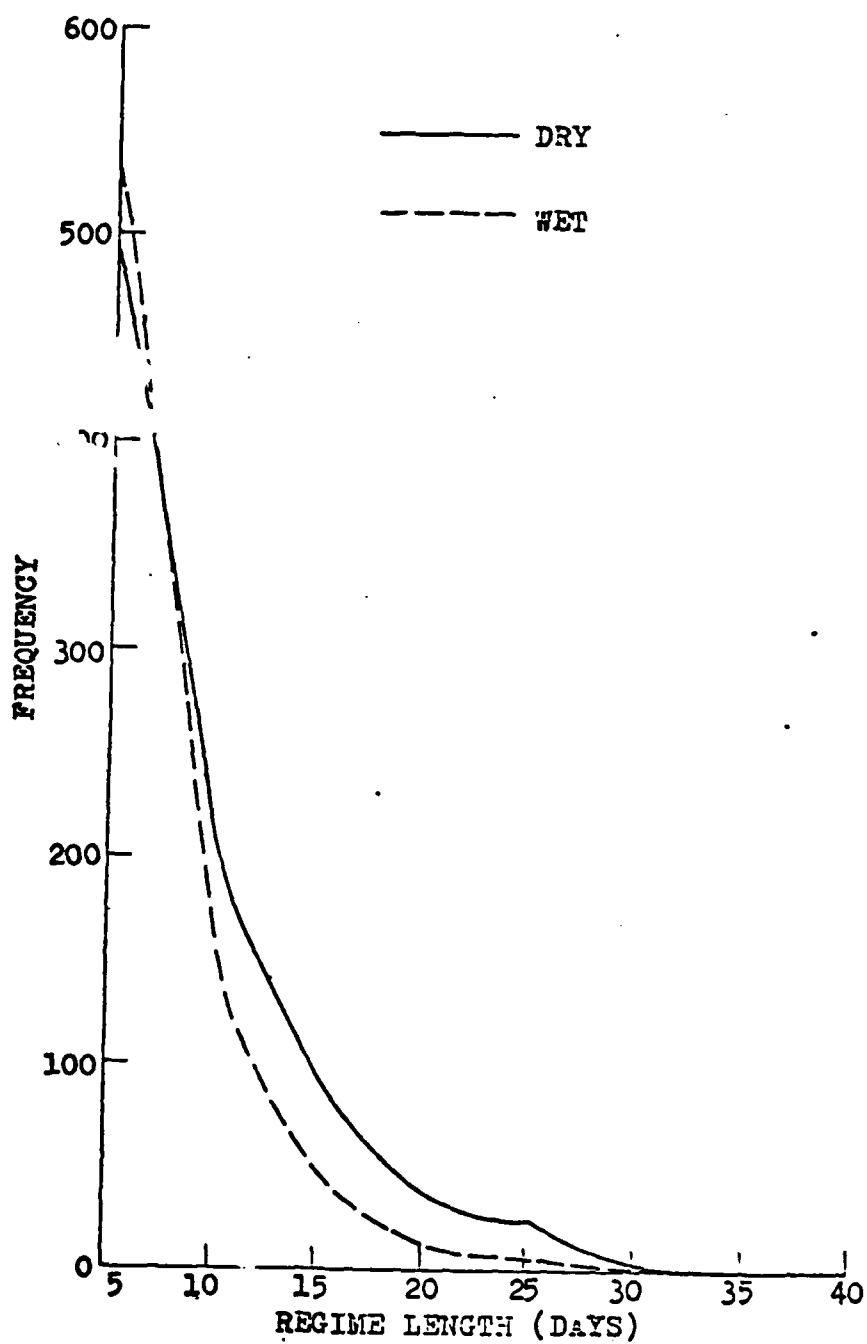


Figure 20. Frequency diagram of the lengths of dry (solid line) and wet (dashed line) regimes for the period 1930-1979.

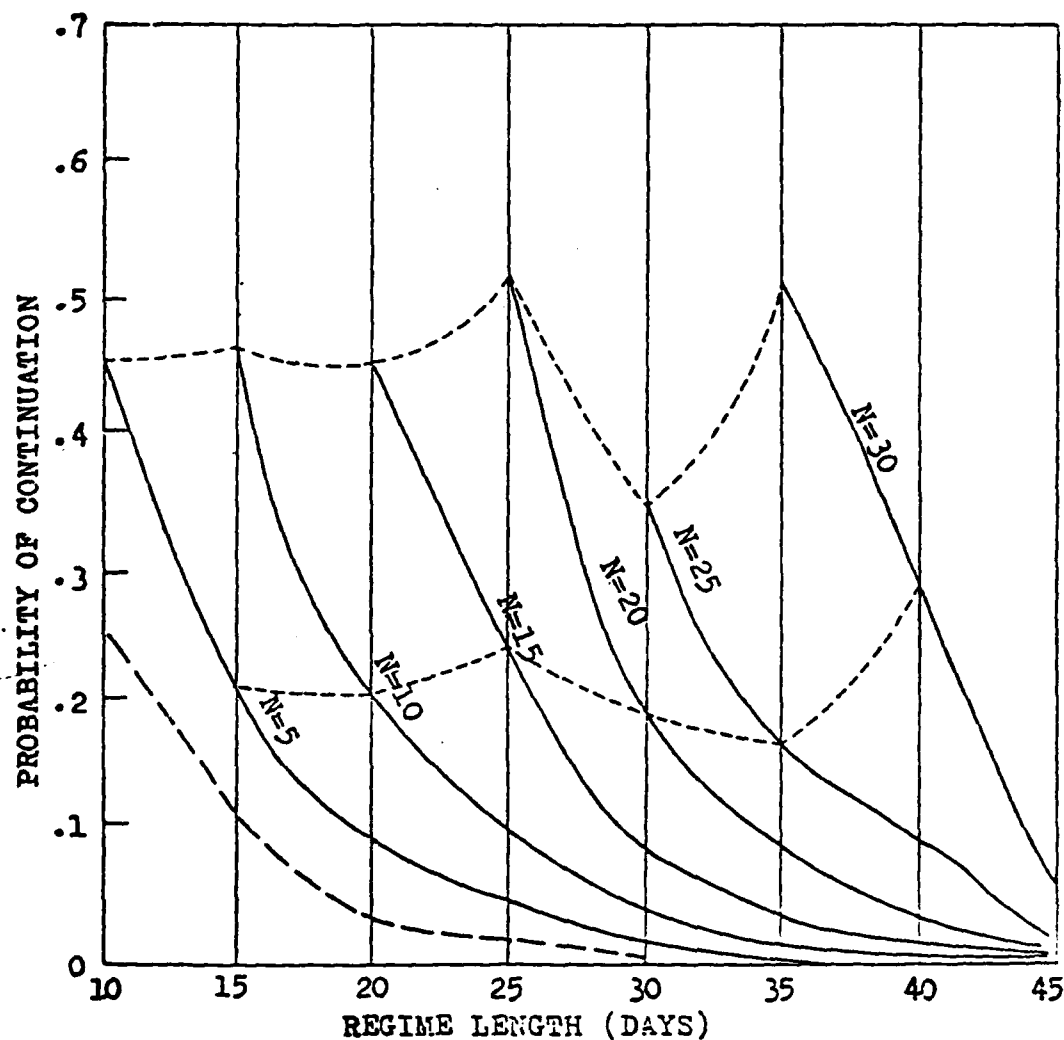


Figure 21. Probabilities of continuation of a dry regime. N is the number of dry days that have occurred, the dashed line is the climatological probability, and the dotted line is the period-to-period persistence probabilities.

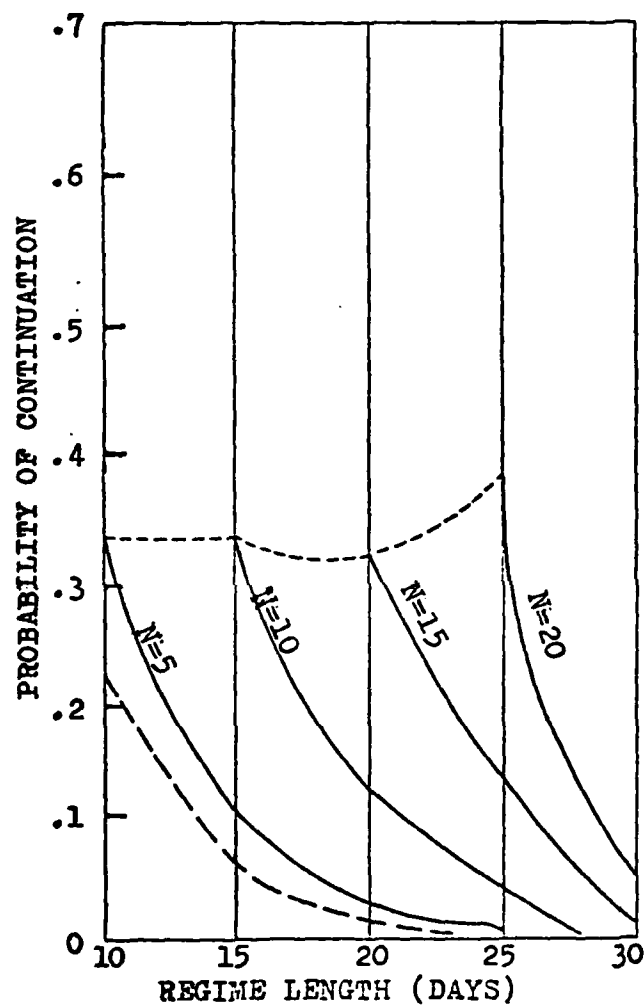


Figure 22. Probabilities of continuation of a wet regime. N is the number of dry days that have occurred, the dashed line is the climatological probability, and the dotted line is the period-to-period persistence probabilities.

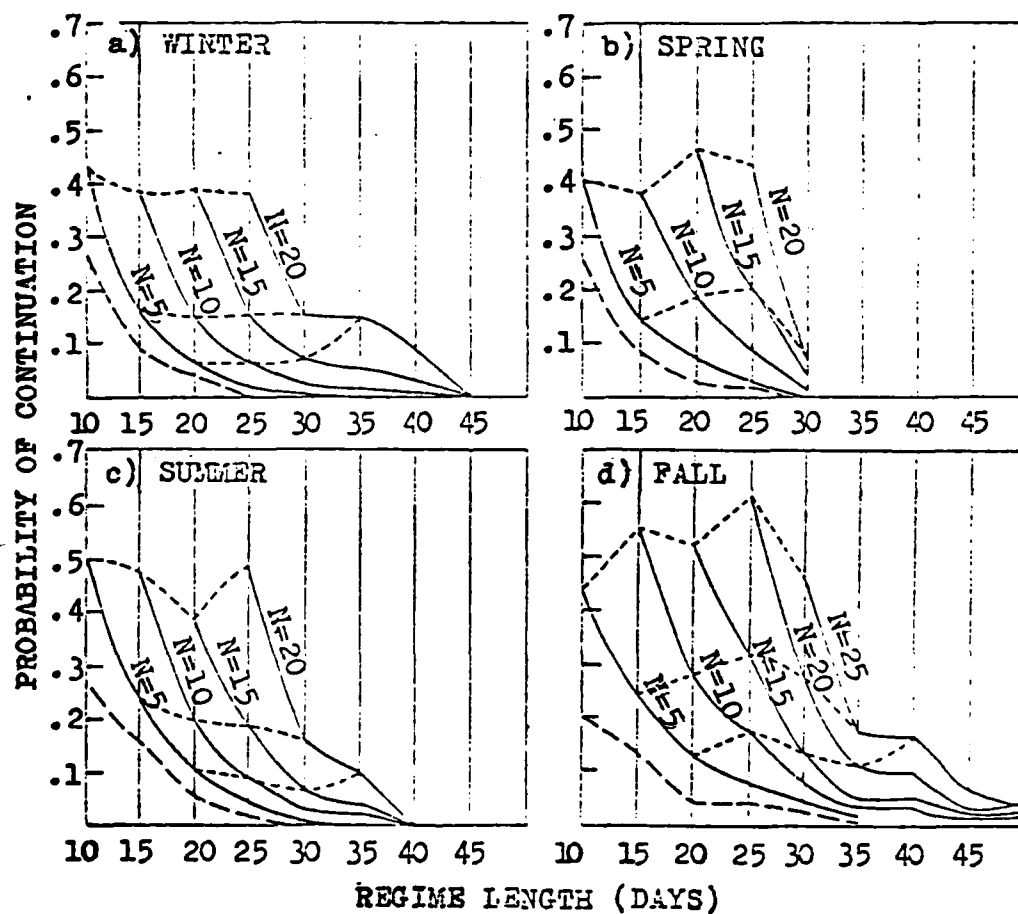


Figure 23. Probabilities of continuation of a dry regime for each season. N is the number of dry days that have occurred, the dashed line is the climatological probability, and the dotted line is the period-to-period persistence probabilities.

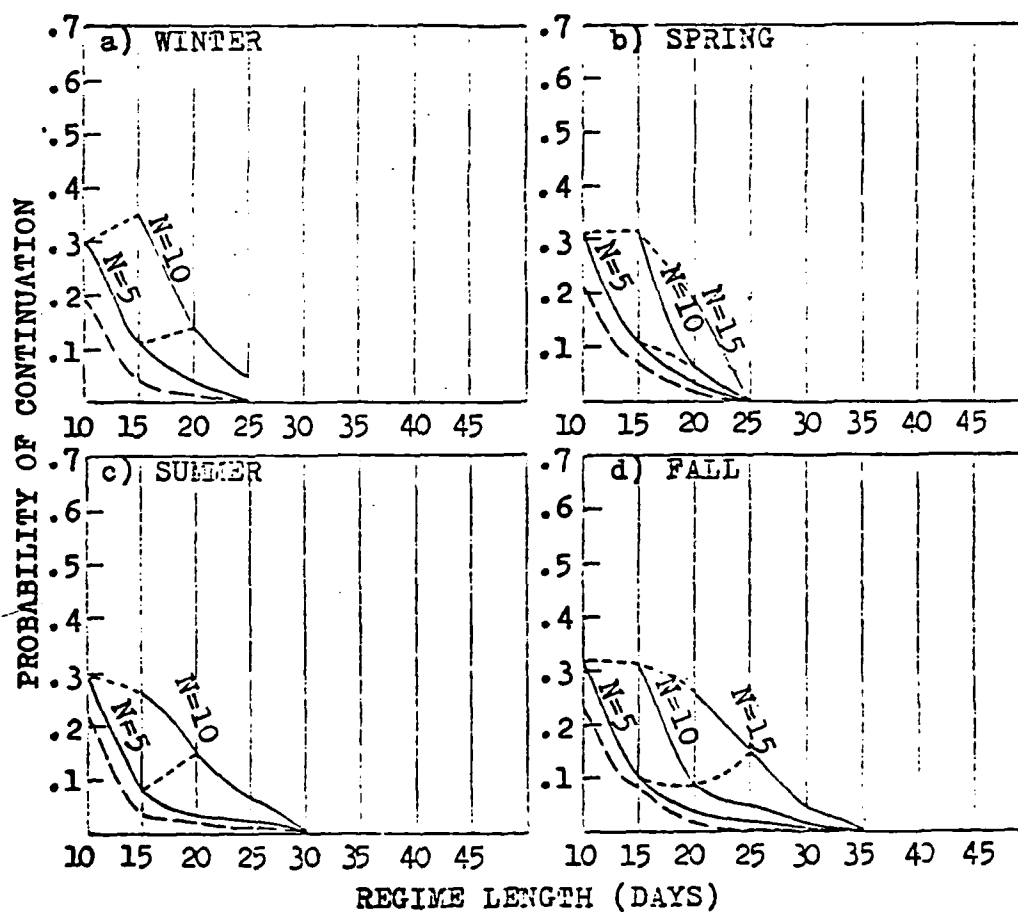


Figure 24. Probabilities of continuation of a wet regime for each season. N is the number of wet days that have occurred, the dashed line is the climatological probability, and the dotted line is the period-to-period persistence probabilities.

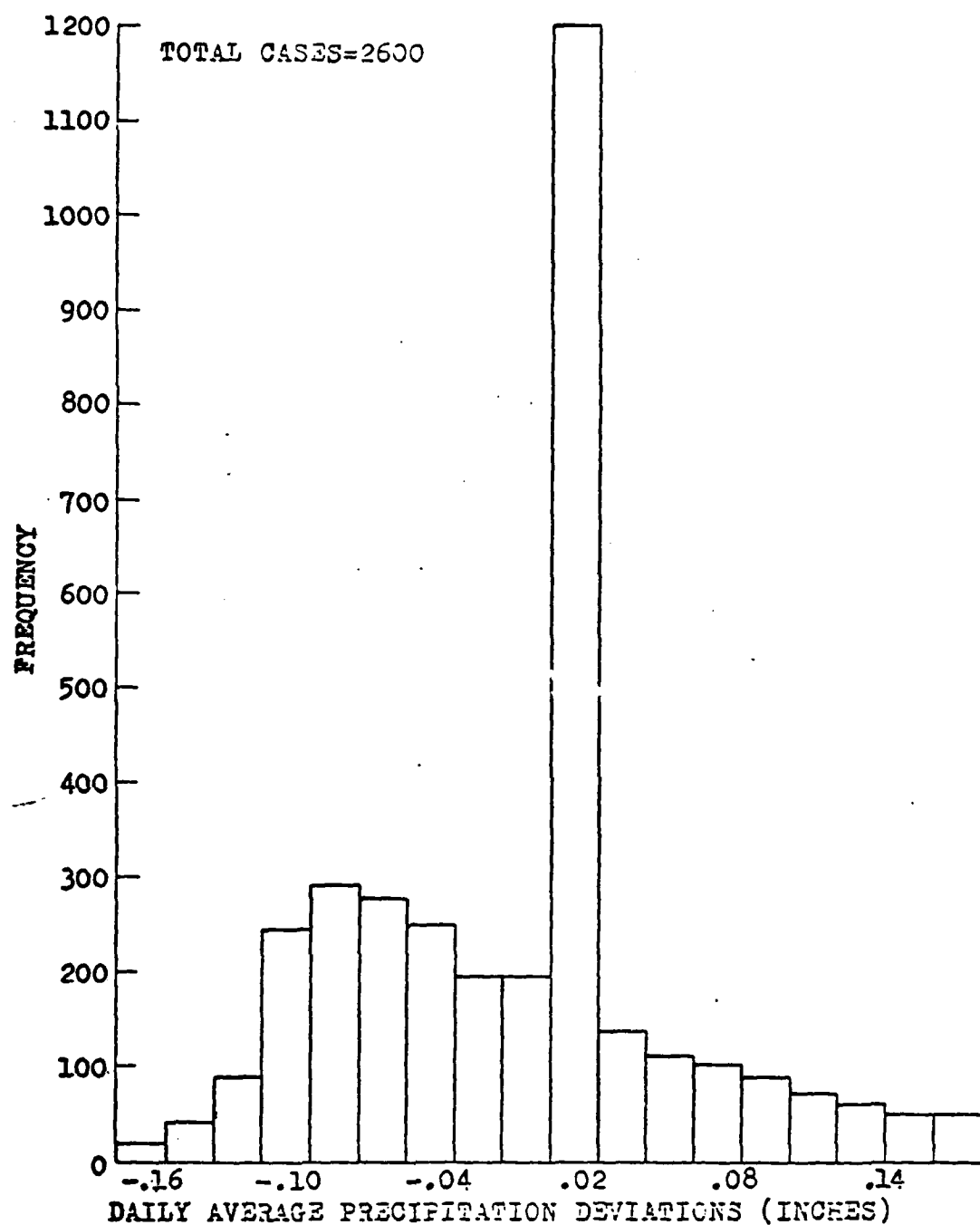


Figure 25. Histogram of the daily average precipitation deviations for seven-day periods for the period 1930-1979.

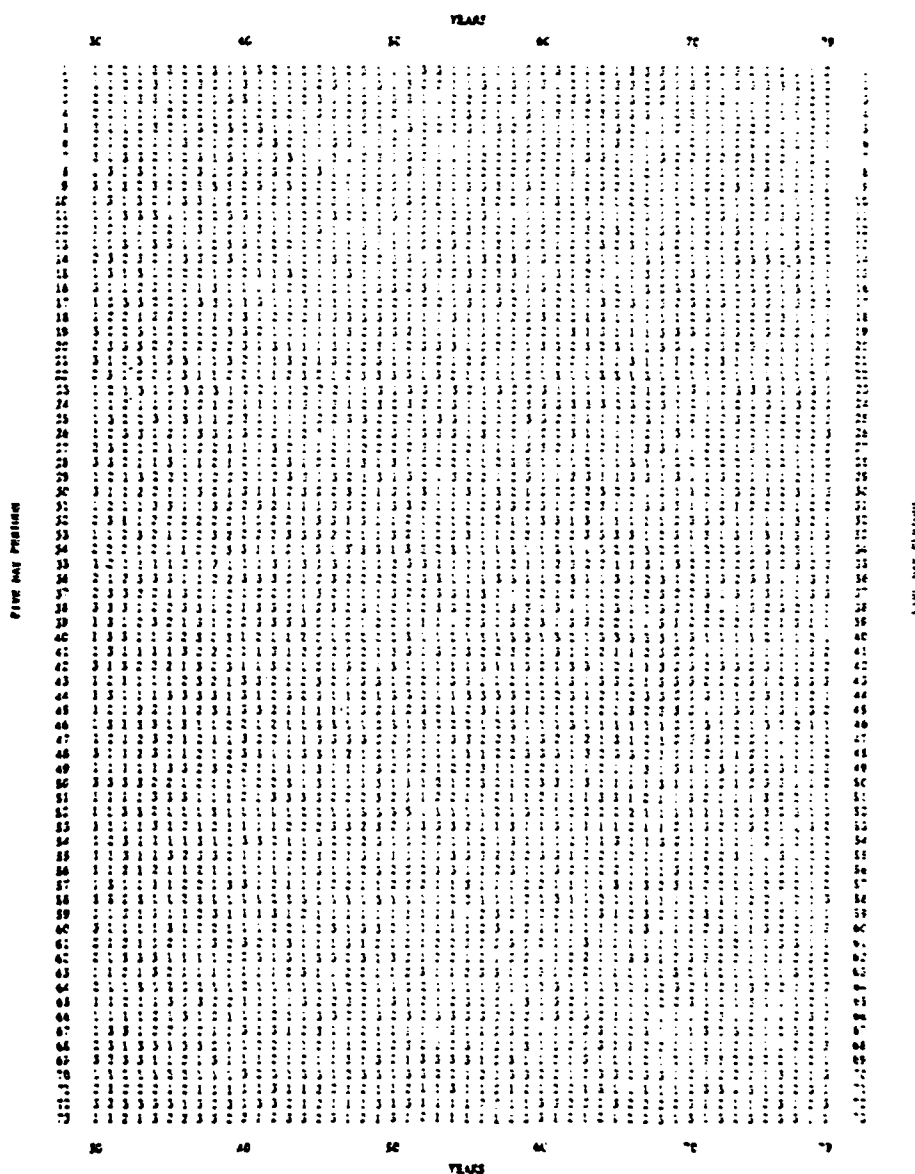


Fig. 26. Comprehensive portrayal of each five-day period for the 50-year period according to the threshold values for dry (1), wet (2) and normal (3).

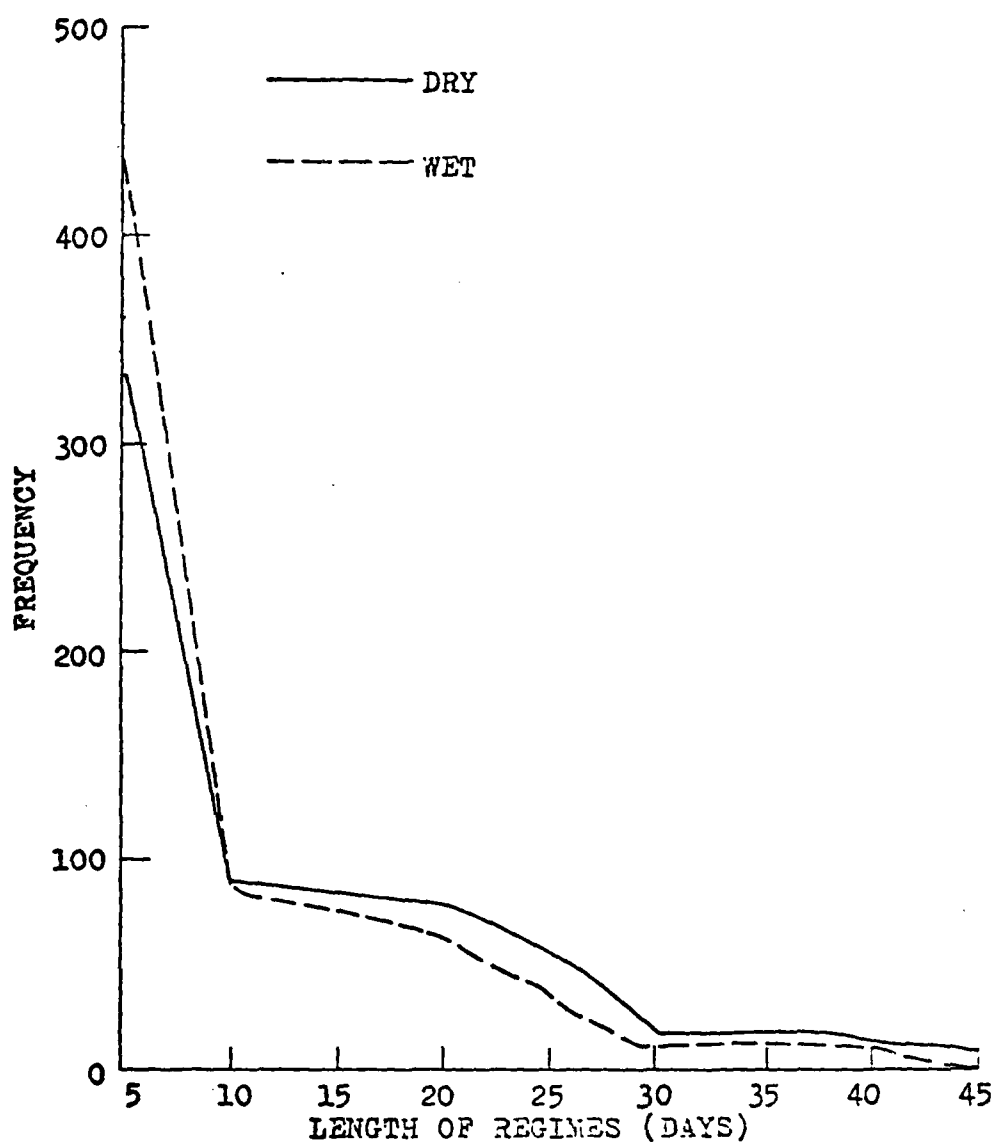


Figure 27. Frequency diagram of the lengths of dry (solid line) and wet (dashed line) regimes for the period 1930-1979.

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EVALUATION OF EXTENDED PERIOD FORECASTING TECHNIQUE.(U)

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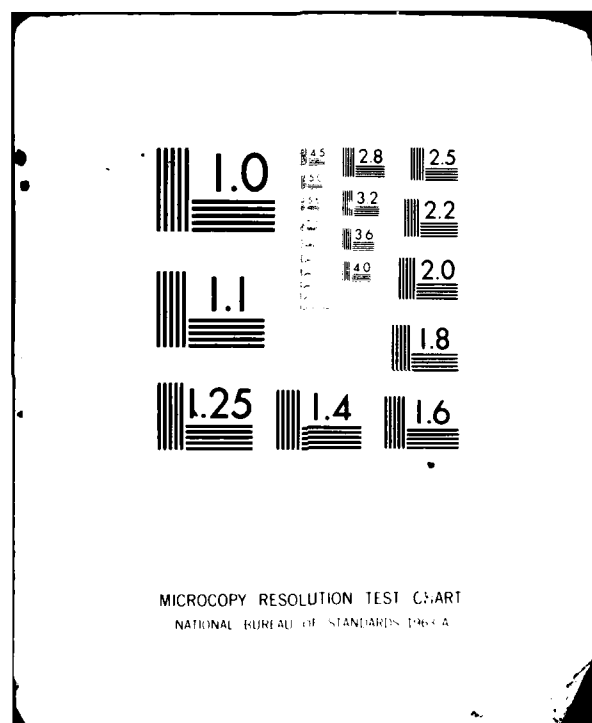
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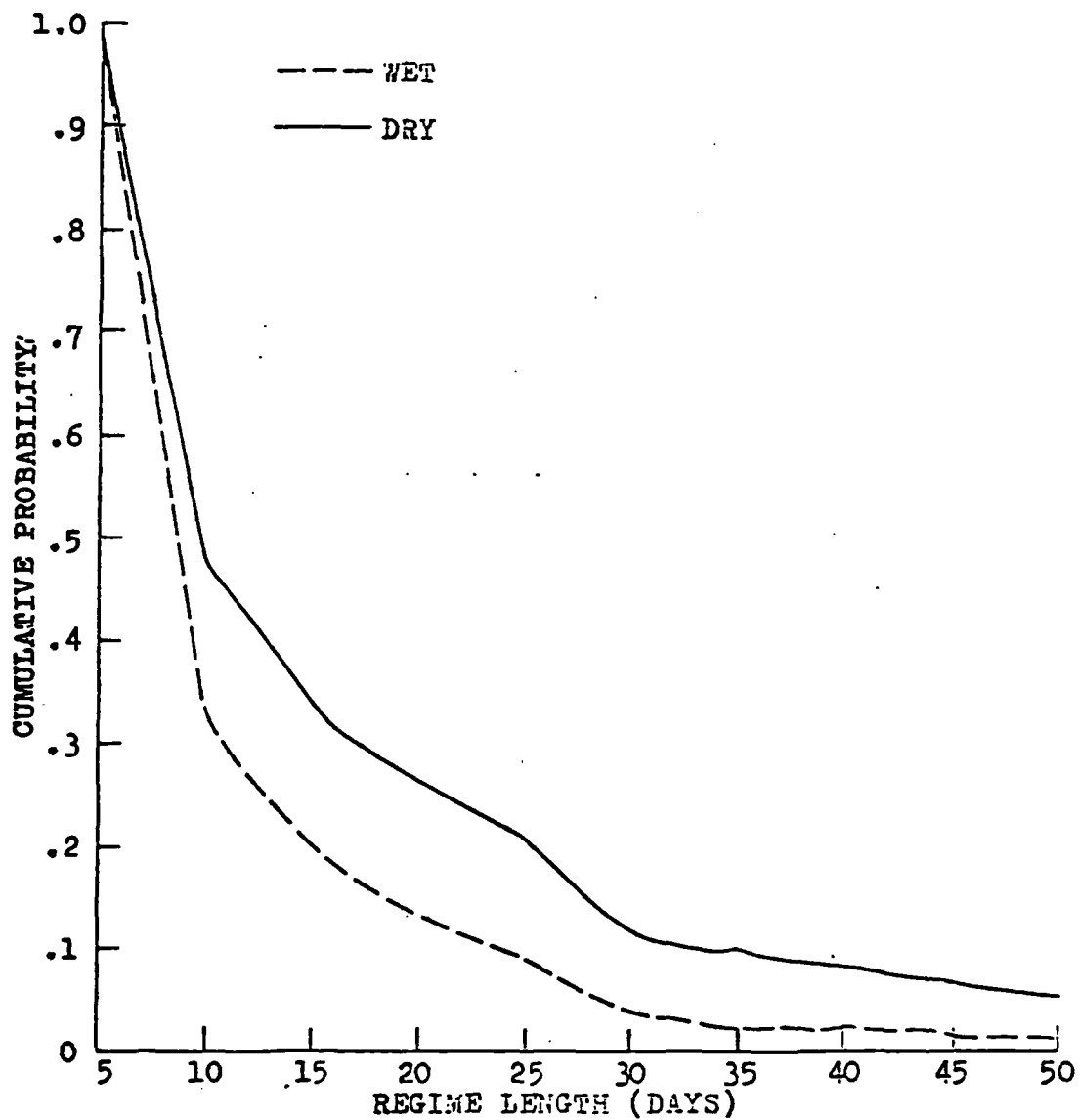


Figure 28. Cumulative probability of regime continuation for five-day dry (solid line) or wet (dashed line) regimes with short breaks.

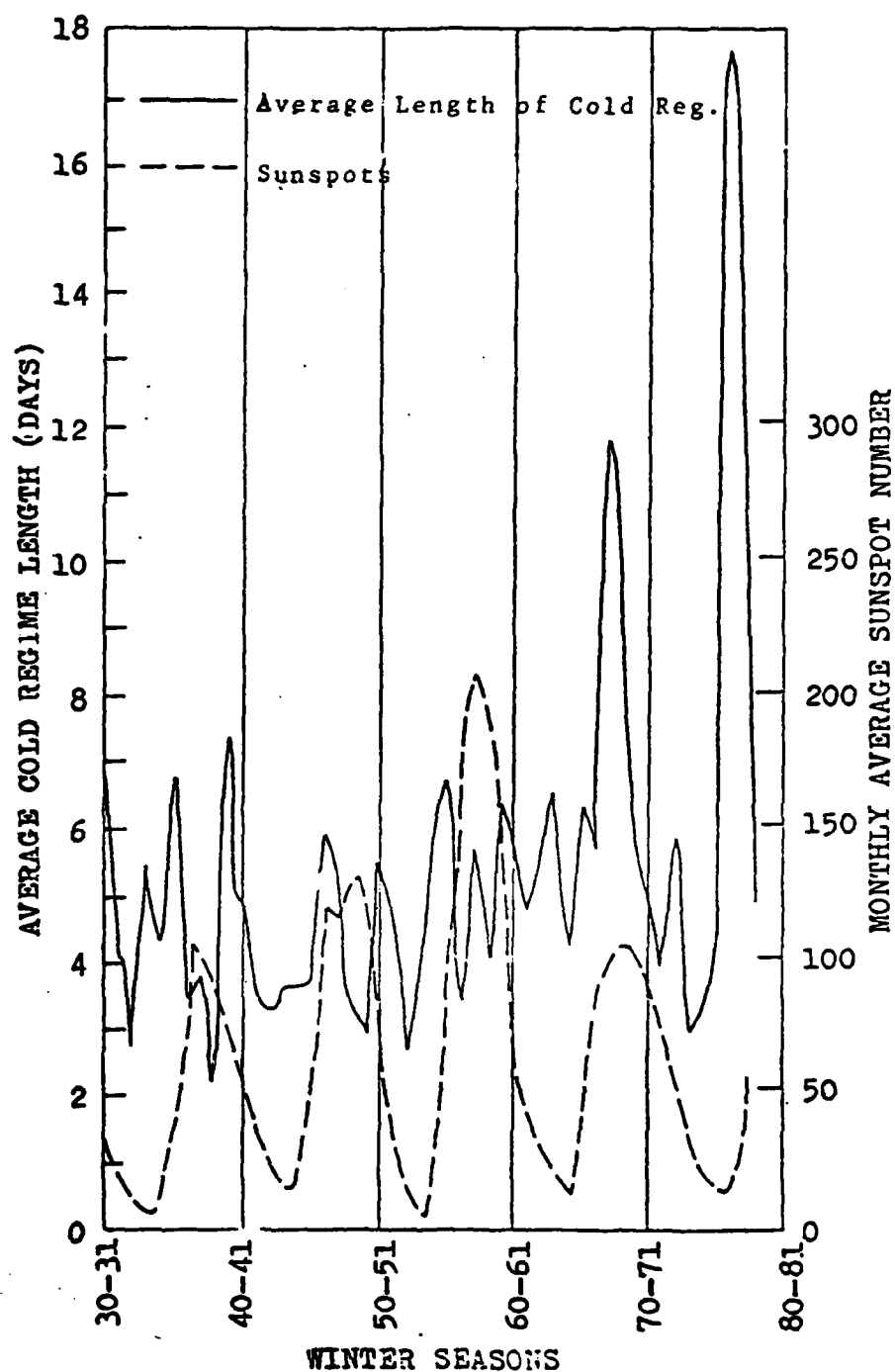


Figure 29. Plot of monthly average sunspot number against the average length of cold regimes for each winter season.

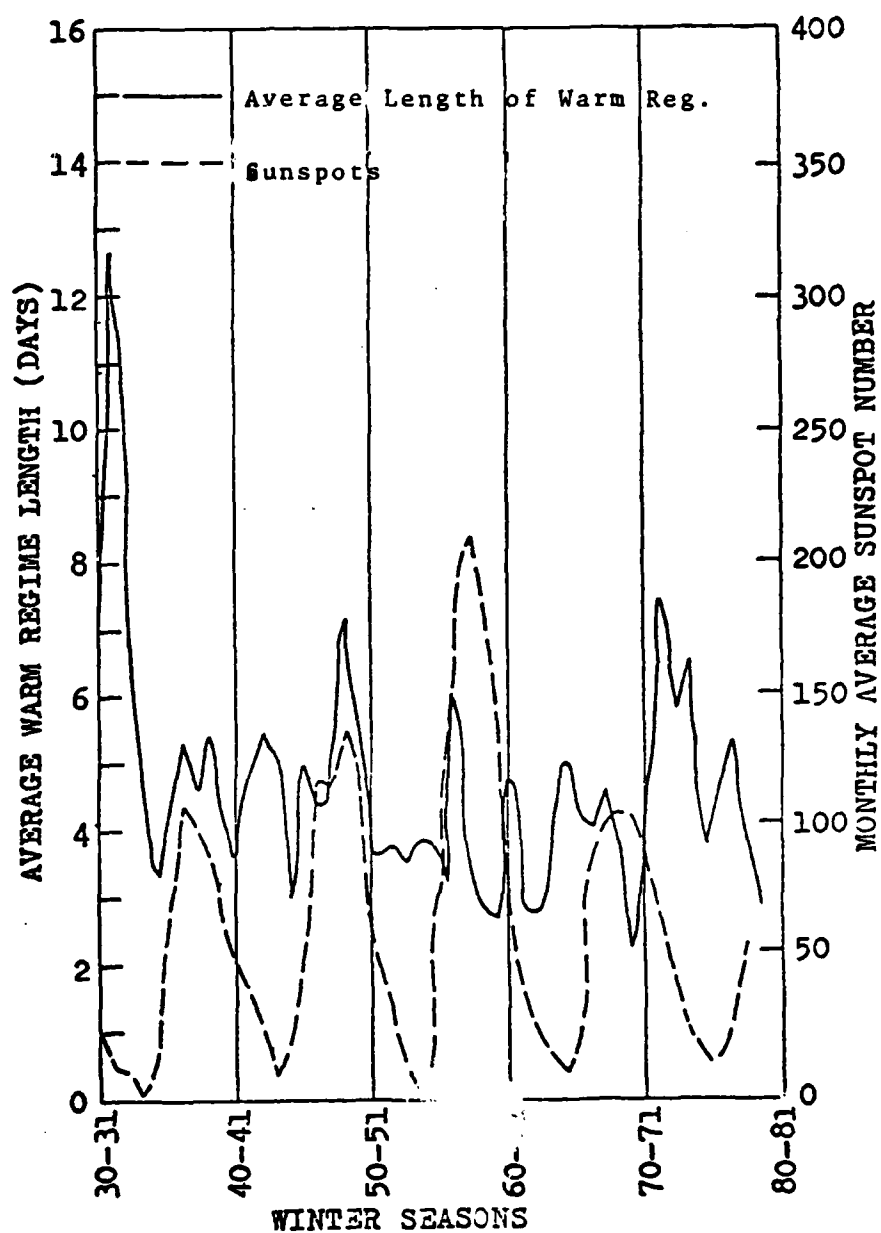


Figure 30. Plot of monthly average sunspot number against the average length of warm regimes for each winter season.

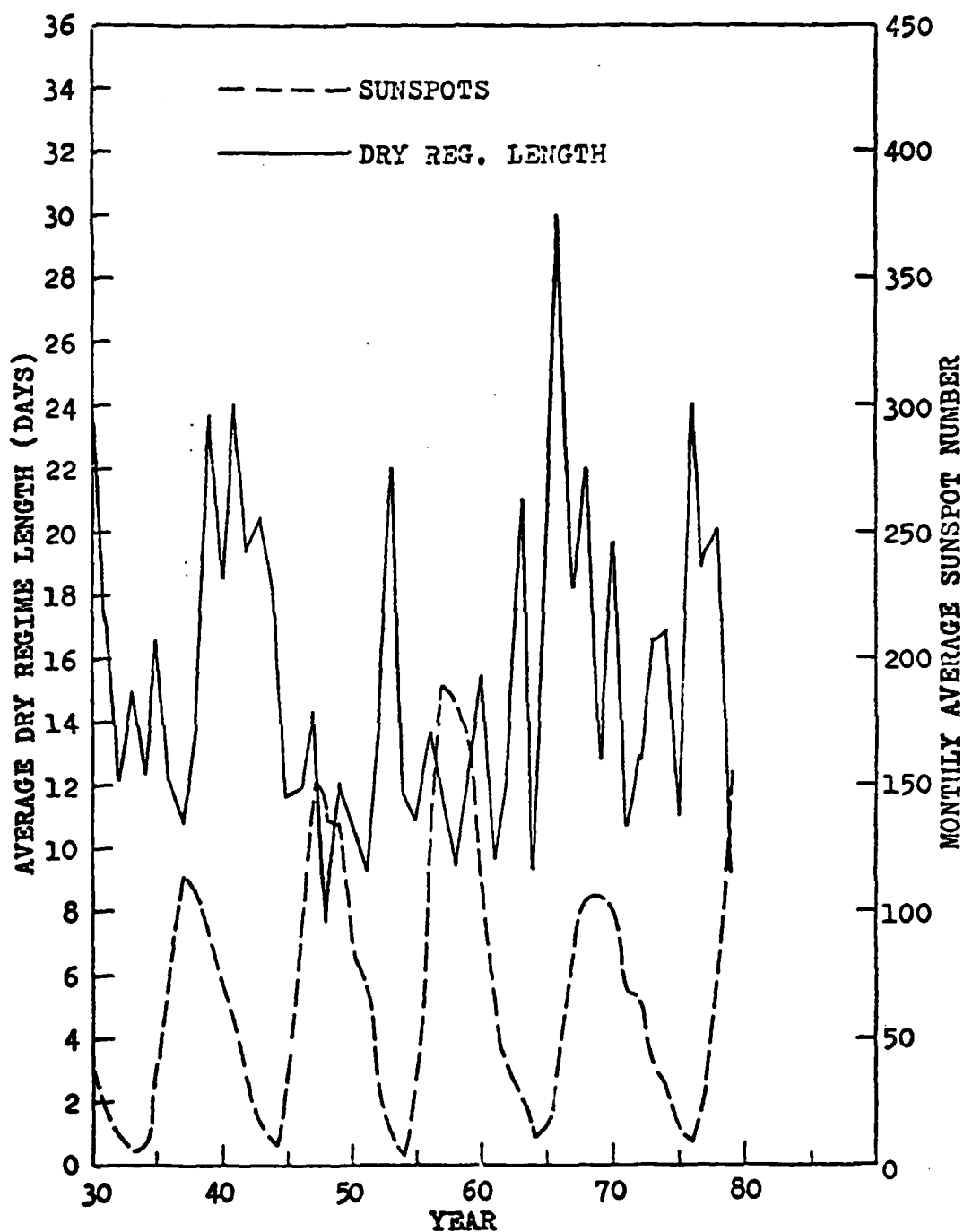


Figure 31. Plot of monthly average sunspot number against the average length of dry regimes for the period 1930-1979.

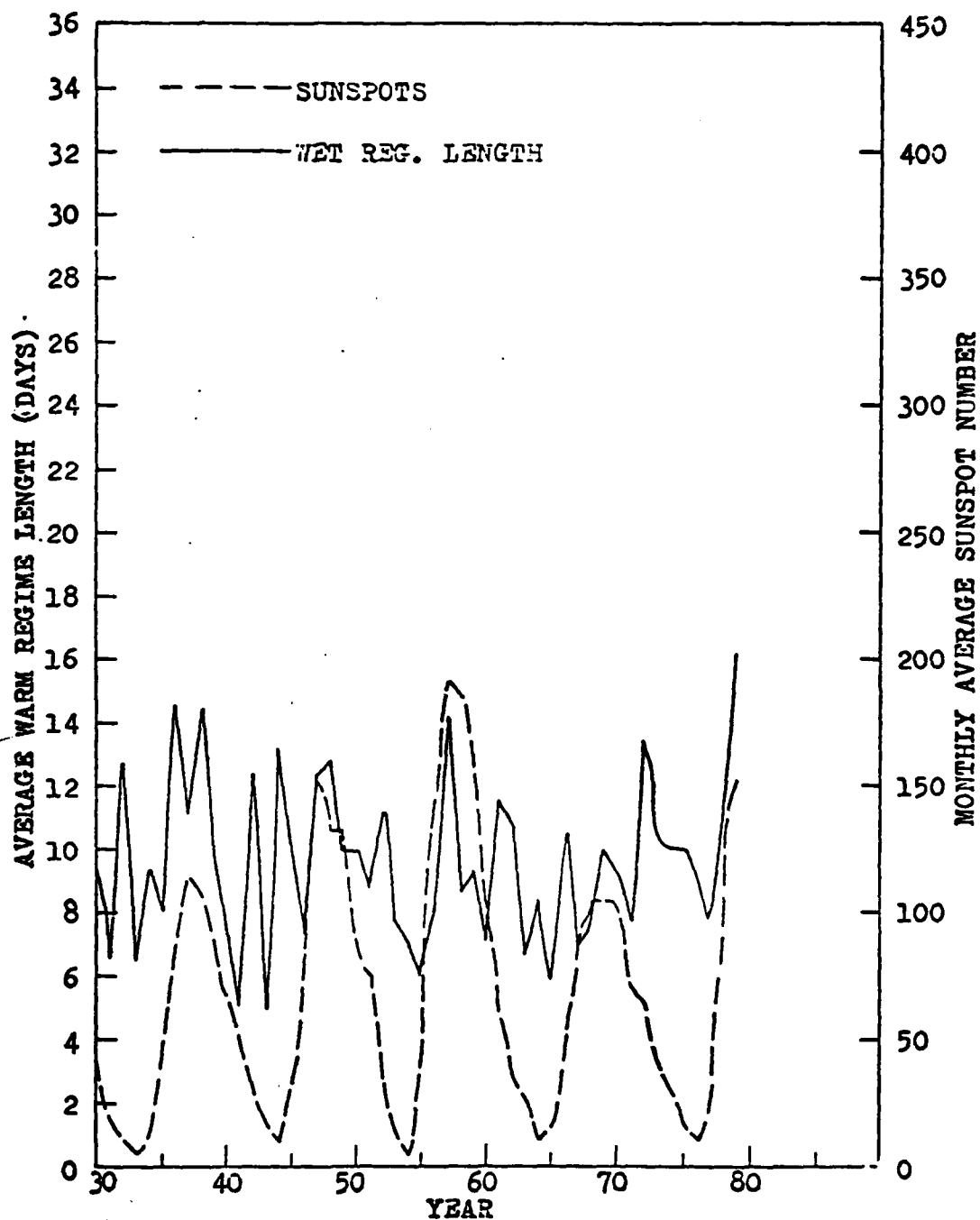


Figure 32. Plot of monthly average sunspot number against the average length of wet regimes for the period 1930-1979.

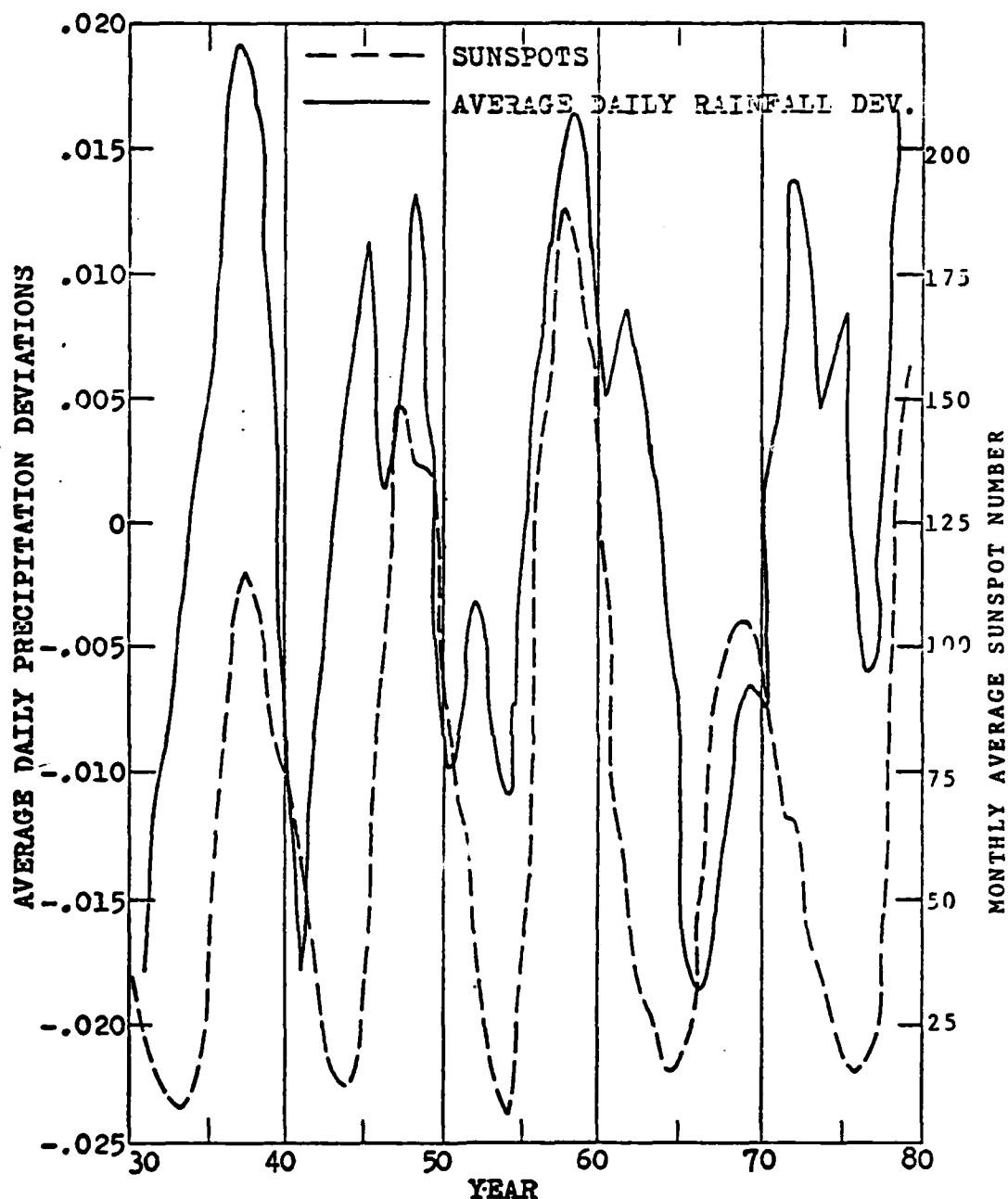


Figure 33. Plot of monthly average sunspot number against the average daily precipitation deviation for five-day periods for the period 1930-1979.

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SECTION IV

PHYSICAL CONCEPT OF PROCESS BY WHICH
TERRESTRIAL CLIMATE IS INFLUENCED BY
VARIATIONS IN SOLAR ACTIVITY

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PHYSICAL CONCEPT OF PROCESS BY WHICH TERRESTRIAL
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Weather and Climate
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SYMPOSIUM/WORKSHOP
ON

SOLAR TERRESTRIAL INFLUENCES ON
WEATHER AND CLIMATE

Fawcett Center for Tomorrow
The Ohio State University
Columbus, Ohio 43210

July 24 - 28, 1978

Panel Members:

Murray Mitchell - NOAA Environmental Data Service

Earl Kindle - Old Dominion University, Norfolk, Virginia

Michael Schlesinger - Oregon State University

Alan D. Hecht - Climate Dynamics Program, National Science Foundation

PHYSICAL CONCEPT OF PROCESS BY WHICH TERRESTRIAL CLIMATE
IS INFLUENCED BY VARIATIONS IN SOLAR ACTIVITY

In view of the tremendous societal yield that would accrue from improvement from medium, long range and climatic forecasts, we, of the meteorological profession, have been perhaps somewhat remiss in the scope of attention that has been addressed to these important problems. For many years Jerome Namias and his colleagues have borne the primary burden for the development and application of extended forecasting techniques. And while pursuing these avenues it was not a totally lonely path but it was certainly not crowded.

Perhaps spurred by recent weather and climatic trends, as well as the availability of data from remote and extra-terrestrial sources, climatologists and our fellow solar physicists have been providing a new leadership in delving into past records as well as some of recent information available on solar output variability.

Dynamic and synoptic meteorologists have perhaps shied away from intensive investigations of the influences of solar variability on terrestrial weather because there seemed to be no way to explain how the magnitude of temperature intensity variations induced by solar variability could account for any significant terrestrial weather behavior. It is true that since the time of Dr. Charles Abbot, and even before, periodic statistical studies have suggested correlations in solar behavior and the earth's weather processes. For the most part these relationships have proven to be very subtle. In fact, many meteorologists have attacked these relationships and have assumed the role of active skeptics. Another large part of

the meteorological profession, while not actively voicing dissent, definitely belonged to a skeptical group.

Recent studies by Jack Eddy in associating long term climatic periods with measurement of carbon and tree rings and other data, prompt our profession to have another look. While these results may not be totally compelling, they are certainly a long way past being merely suggestive. Similarly, Murray Mitchell's correlation of the area covered by 22 year drought cycles in the American West, with solar variability, intensifies the demand that we take a wider look. Walter Roberts, Roger Olson, and John Wilcox have strongly supported this trend by their showing very positive correlations of vorticity area index variability for The Aleutian Lows with magnetic sector boundary crossings. From the abstracts of papers at this meeting these positive viewpoints seem to be supported by several independent efforts. Basart, Yarger and Rheinhold Reiter, in independent studies, offer some strongly supporting evidence that stratospheric intrusions or terrestrial circulation patterns are related to variability in solar flares and magnetic sector crossings. Ramakrishna, as well as McFarland and Panaka, are supporting distinct correlations of temperature and pressure with solar variability. Kelly and King with studies of North Atlantic and European cyclonic and anti-cyclonic circulation behavior, are presenting data that are consistent with Roberts, Olson and Wilcox results. Shaefer and Quate are both showing additional strong support from statistical relationships between the frequency between certain synoptic types

and solar weather. Schuurman has similar relationships that relate tropospheric intrusions at key locations 2 - 4 days after solar flares.

Ralph Markson and Mac Lethbridge have shown some compelling correlations between atmospheric electricity conditions and perhaps thunderstorm frequency as associated with solar activity. While the direct linkage between the variability of atmospheric electric fields and the hydro-dynamic behavior of the atmosphere is not yet clear, Markson offers a very plausible explanation of how solar effects could influence the earth's electrical field.

Of course, these statistical relationships are subtle and the levels of significance are sometimes open to question. On the other hand, we should be more concerned if relationships were very strong and indicate that the solar variability was a dominant factor, or even a large factor, in the earth's weather variability. That is, the atmosphere is much too complex and involves too many strong forcing functions acting on a number of large potential and kinetic energy reservoirs in the atmosphere, ocean and earth with a wide range of capacities and response times. These large forcing functions and reservoir responses, in turn, affect the spatial and temporal frequencies with complicated nonlinear interaction and feedback problems. Nonetheless, with the statistical results to date, it is clear that some model concepts of how the atmosphere can react to solar variability forcing are badly needed; if for no other reason, to lend more precision to the development of downstream statistical approaches.

We, at Old Dominion, have been working for over a year in relating sunspot variability to frequency of preferred synoptic patterns and similarly get the same type of subtle correlations that have been reported by others. With availability of large scale computer capacity we have stratified and changed our predictands and predictors in numerable ways trying to derive more significance in the relationships. However, it appears that we get very little improvement no matter how we change our statistical approach. Not that we have exhausted all the possibilities; in fact, it seems that there are an infinite number of statistical approaches one could choose almost at random and we have become convinced that the likelihood of stumbling onto more meaningful results by continuing this approach ad infinitum is not very likely. We have concluded that a major effort must be undertaken at this time to draw upon the statistical data we have available and try to derive some type of a reasonable model or physical concept of how the atmosphere can be influenced in a significant way by solar variability. Even a small success in this area would help us select more precise statistical approaches that would have a higher probability of success which in turn could help us define better concepts and models, etc.

We agree that if a direct hydrodynamic magnitude of density and temperature changes induced by solar variability is inconsistent with the scale of the circulation variability that seems to be statistically correlated. We probed and considered several possibilities. Naturally an appealing first approach

would be variations in the Hadley Cell circulation which would of course be a very important factor. However, at the present time there are seemingly no statistical approaches that are consistent with such a premise.

We next considered several hypotheses in which variable solar output might affect properties of the Ferrel Cell. One concept that emerges from a review of the statistical results presented at this meeting is that the intensity or amplitude of the planetary and synoptic scale perturbations in the Ferrel Cell are greater during solar activity years than in moderate or weak solar years. If we reject hypotheses that require major changes in the earth's available potential energy as induced by solar activity variability, we must establish a "triggering affect" or possibly a mechanism by which the small solar fluctuations change the way in which the atmosphere itself converts potential to kinetic energy. The latter concept has some appeal because the earth's atmosphere has an abundant amount of unused available potential energy which would be converted more rapidly to kinetic energy by critical changes of the atmosphere's static stability.

We considered possible variations in monsoon circulation strengths induced by changes in solar energy received at the earth's surface. We considered possible changes in the seasonal inter-hemispherical changes as induced by possible greater differences in the northern and southern hemispherical heat budgets. We also looked into possible effects of stratospheric warming which might be induced by increased ultra violet radiation. None

of these probes provide a clear path from syllogism to ergo. However, the last seem to be consistent with some evidence that there are increases in ultra violet radiation in solar active years amounting to as much as 10 - 30 percent. Further, marked warming of the middle and upper stratosphere has been observed and seemingly may be associated with the increases in solar activity.

This warming of the stratosphere, if it amounted to as much as ten degrees and reached as low as 25 km, could produce a resulting increase in the static stability of the lower stratosphere. A priori, we would tend to associate increased static stability with weaker Ferrel Cell perturbations. However, most models describing this effect are referring to the stability of the troposphere. Depending on the order of magnitudes and the timing between the conversion of potential and kinetic energy in the stratosphere and troposphere we suggest the following concept as a possible mechanism for the increase of troposphere perturbations amplitude during periods of higher solar activity.

We shall first assume that the middle stratosphere is warmed substantially by the increase in ultra violet radiation. The mass of atmosphere involved is small enough that conceivably the 10 - 30 percent variation and radiative intensity could account for the presumed 10 degree warming. We shall consider east/west perturbations in the Ferrel Cell as structured as indicated in Figure 1a and 1b. Figure 1 portrays a planetary wave characteristic of mid-latitude systems in which lower troposphere convergence and

divergence over lows and highs respectively are offset with upper troposphere and lower stratosphere divergence and convergence respectively. Over the low pressure system there are rising currents throughout the troposphere meeting a subsiding current from the stratosphere at the tropopause which results in a lowering of the tropopause over low pressure area. This lowering of the troposphere over low pressure systems is a significant contributor to the intensity of the low and hence to the cyclonic circulation in the troposphere. Conversely, convergence at upper levels over anticyclones is associated with descending air below the tropopause matched by an ascending motion in the stratosphere. This produces rotating cells between ridges and troughs in a zonal vertical plane in the troposphere with a reverse counterpart cell above in the stratosphere. This factor contributes to a raised tropopause over anticyclones and contributes to the intensity of the troposphere anticyclone.

If we would suddenly increase the stratospheric temperature by 10 degrees in the vicinity of 20 - 25 km, the vertical circulation cells would tend to converge this new source of warm air over lows and deplete it over highs. The sinking motion over lows would then tend to contribute a lowering of the pressure in the troposphere. The converse of this effect would be presumed to take place over the anticyclones.

We suggest that this decrease of pressure over lows and the increase in pressure over highs in the troposphere would lead to an increase in the intensity of the planetary waves and hence an increase in the perturbation kinetic energy of the troposphere.

This increase of kinetic energy would be transmitted to the lower stratosphere which would reinforce the intensity of the vertical circulations described previously. This in turn would contribute to a further increase in the concentration of warm stratospheric air over lows and cooler stratospheric air over highs.

This hypothesis is, of course, speculative and has several potential pitfalls in that it assumes that a large portion of tropospheric kinetic energy is transmitted to the stratosphere by turbulent diffusion which in turn creates the ageostrophic motion which causes outflow over lows and inflow over highs in the lower stratosphere. This in turn provides the source of the reverse vertical circulations that are observed in the stratosphere. It is through these vertical currents in the stratospheric air you have rising cool air and sinking warming air that kinetic energy is converted to potential energy. Clearly, a more stable stratosphere would more readily dampen the kinetic energy in these vertical cells by permitting a more rapid conversion to potential energy. It is here that the order of magnitudes, time lags and other factors must be considered. That is, does the new static stability dampen the kinetic energy in the vertical cells so rapidly that no significant decrease in the pressure column over lows is realized; or could the effect produce the intensification of tropospheric pressure systems and thereby create an increase in the perturbation kinetic energy which is in turn transferred to the stratosphere to maintain the source of kinetic energy in the stratospheric vertical cell which is needed to drive the systems. We propose to investigate this problem in two ways. The first is again statistical

in which we shall try to correlate the amplitudes of wave numbers 4 - 8 with the solar output cycles; second we shall develop a simple two-dimensional (longitude vs height) model, coupling the stratosphere and troposphere to determine the differences, if any, in troposphere baroclinic development under two regimes of stratospheric stability. We shall, of course, make some preliminary studies with linearized versions of the model to search for some analytic relationships.

A further interesting facet of the hypothesis that Ferrel Cell perturbations have a larger amplitude in solar active years than in inactive years is that such a systematic change in circulation patterns could be consistent with some well-known climatic changes. For example, in the solar active years we would have larger Ferrel Cell perturbations that would bring about more effective heat exchange between northern and southern latitudes, but also it would imply that these larger amplitude perturbations would be associated with lowered intensities of the zonal circulation and would set up the persistent regimes that makes one portion of the earth unusually cold while another of comparable latitudes unusually warm. The more interesting case, however, would be in the solar inactive years when the Ferrel Cell perturbations are at a minimum. Here the north/south heat exchange would be reduced. This would result in a warming of the lower latitudes and a cooling of the more northerly latitudes. This would be reflected in adjustment in the radiation balance which suggests two important factors. One is the nonlinear effect in the earth's

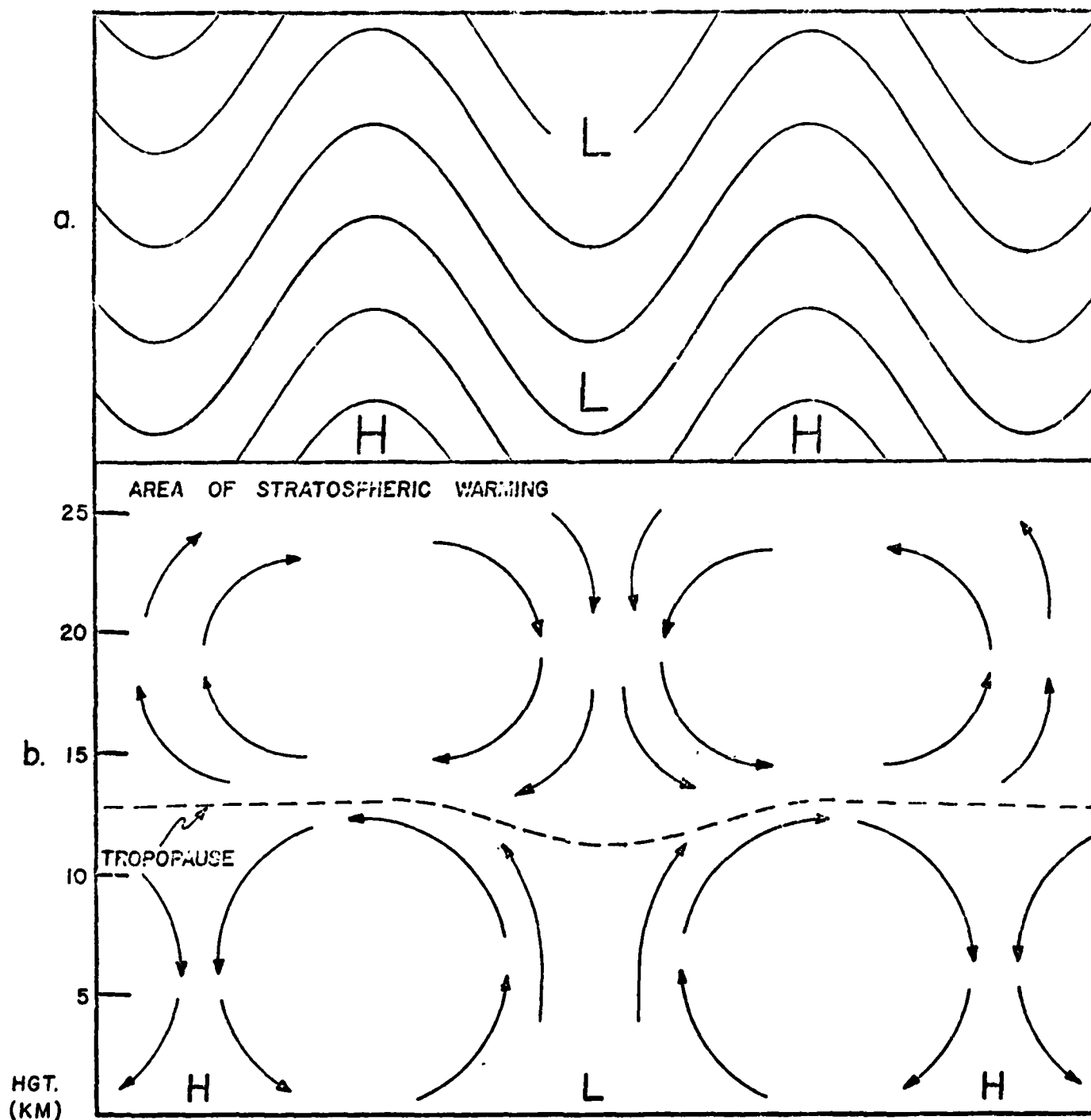
radiation balance; that is, with development of a new heat balance induced by a weakened north/south heat exchange the temperature increase of the lower latitudes would be less than the corresponding decrease of temperature of high latitudes. The second factor has to do with the relative areas of the surplus and deficiency of the solar terrestrial heat exchange. It is estimated that the whole area of the earth equatorward of 37° latitude receives more heat from the sun than it radiates to space, while the converse is true of poleward of 37° latitude. Since the lower latitude's increased radiation in the new balance would be derived from about 60% of the earth's surface and the northern latitude's decrease in radiation must be realized from only about 40% of the earth's surface, the increase in low latitude temperatures would be considerably smaller than the decrease in higher latitude temperatures. The nonlinear effect of the fourth power radiation law mentioned above would make possible a decrease in the earth's mean temperature with a decreased north/south transport of heat even without any change in net solar output.

This decrease in mid-latitude temperatures supplemented by the decrease associated with the difference in the areas of surplus and deficiency radiation would contribute to a colder earth and even colder regimes in mid-latitudes. This, of course, is not inconsistent with the colder years of the Maunder Minimum and the colder climatic regimes that Jack Eddy has associated with the low sunspot years.

I realize that this proposed mechanism is highly speculative and ordinarily would require a great deal of checking and probing

before presentation to one's scientific colleagues, particularly such a gathering as this one. However, as I stated earlier, I believe our investigation of solar terrestrial relationships is now at a plateau and can only go forward if we develop some kind of understanding of the physical mechanisms involved. For that reason I believe that it is incumbent upon dynamic and synoptic meteorologists to start presenting their ideas even though they are only half way between speculation and hypothesis.

FIGURE 1



a. CHARACTERISTIC PERTURBATION IN MID-LATITUDE WESTERLIES

b. ASSOCIATED VERTICAL CIRCULATION PATTERN

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